AD-A098 141 AEROSPACE CORP EL SEGUNDO CA F/G 17/5

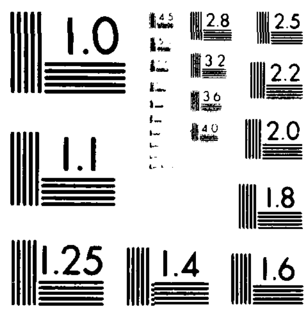
USER'S MANUAL FOR THE PLUME SIGNATURE CODE EAPROF.(U)

JAN 81 S J YOUNG F04701-80-C-0081

UNCLASSIFIED TR-0081(6623)-1 AFRPL-TR-81-08 NL

1 OF 1
AD A098141

END
DATE FILMED
5 81
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

① LEVEL

AD A098141

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFRPL-TR-81-08 — 2. GOVT ACCESSION NO.: AD-A098141	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): User's Manual For the Plume Signature Code EAPROF	5. TYPE OF REPORT & PERIOD COVERED: Interim
	6. PERFORMING ORG. REPORT NUMBER: TR-0081(6623)-1
7. AUTHOR(s): Stephen J. Young	8. CONTRACT OR GRANT NUMBER(s): FO4701-80-C-0081
9. PERFORMING ORGANIZATION NAME AND ADDRESS: The Aerospace Corporation, El Segundo, California	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: JON: 573010CU
11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, California	12. REPORT DATE: Jan[redacted] 1981
	13. NUMBER OF PAGES: 68
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

DTIC ELECTE APR 23 1981 S D B

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Approved for Public Release; Distribution Unlimited.

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Plume radiation

Two-phase plumes

Low-visibility rocket plumes

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A description and instructions for use of the plume signature code EAPROF are given. The code computes the transverse profiles of infrared emission and extinction within a fixed bandpass for an axisymmetric, axially uniform, cylindrical two-phase plume. The principal inputs are the radial distributions of gas temperature, pressure, and concentration and particle temperature and number density. An example application is made for a plume containing H_2O as the gas species and Al_2O_3 as the particle species.

DD FORM 1473 (FACSIMILE)

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

DTIC FILE COPY

81 4 14 .20

AEROSPACE FORM 4341-1 REV 5-74

FOREWORD

This report was submitted by the Aerospace Corporation, P.O. Box 92957, Los Angeles, California, 90009, under Procurement Directive AFRPL/SD 81-1, Job Order No. 573010CU with the Air Force Rocket Propulsion Laboratory, Edwards AFB, California 93523.

This report has been reviewed by the Technical Information Office (STINFO/TSPR) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations. This technical report has been reviewed and is approved for publication; it is unclassified and suitable for general public release.

T. Dwayne McCay

T. DWAYNE McCAY
Research Physical Scientist

Gregory Steven Meserve

GREGORY S. MESERVE, 1Lt, USAF
Project Manager

David M. Mann

DAVID M. MANN
Chief, Plume Technology Branch

FOR THE COMMANDER

Eugene G. Haberman

EUGENE G. HABERMAN
Chief, Propulsion Analysis Division

NOTICE

When U.S. Government drawings, specifications, or other data are used for any purpose other than a definitely related government procurement operation, the government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, or in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture or use, or sell any patented invention that may in any way be related thereto.

CONTENTS

RE: AFRPL-TR-81-08
Pages 3, 4, 8, 13 and 34 were intentionally left blank per Ms. Nancy Chalfant, AFRPL/TSPR

FIGURES

1. INTRODUCTION

Program EAPROF (Emission Absorption Profiles) computes the transverse profiles of infrared emission and extinction for an axisymmetric, axially uniform, cylindrical plume from radial profiles of gas temperature, pressure, and concentration and particle temperature and number density. The radiation model treats gas radiation transfer with band model methods and particle radiation transfer with the single-scattering approximation. The radiation model correctly couples the gas and particle components into a single emitting, absorbing and scattering medium. The program treats just one gas species and one particle species at a time. Development of the model is made in Ref. 1.

The gas band model is the Malkmus statistical model and employs either the Curtis-Godson (CG) or derivative (DR) approximations to handle the inhomogeneity and nonisothermality of the plume. Lorentz, Doppler or Voigt line profiles may be used.

The single-scattering geometry used for particle radiation transport is shown in Fig. 1. The s-axis is the primary line of sight (LOS). (The LOS shown in Fig. 1 is the one that goes through the full plume diameter. As the LOS is scanned out across the lateral extent of the plume, it cuts progressively shorter chords of the cylindrical plume). The σ-axis is the scattering LOS.

---

1. S. J. Young, Retrieval of Flow-Field Gas Temperature and Concentration in Low-Visibility Propellant Rocket Exhaust Plumes, U.S. Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, Calif. (to be published).

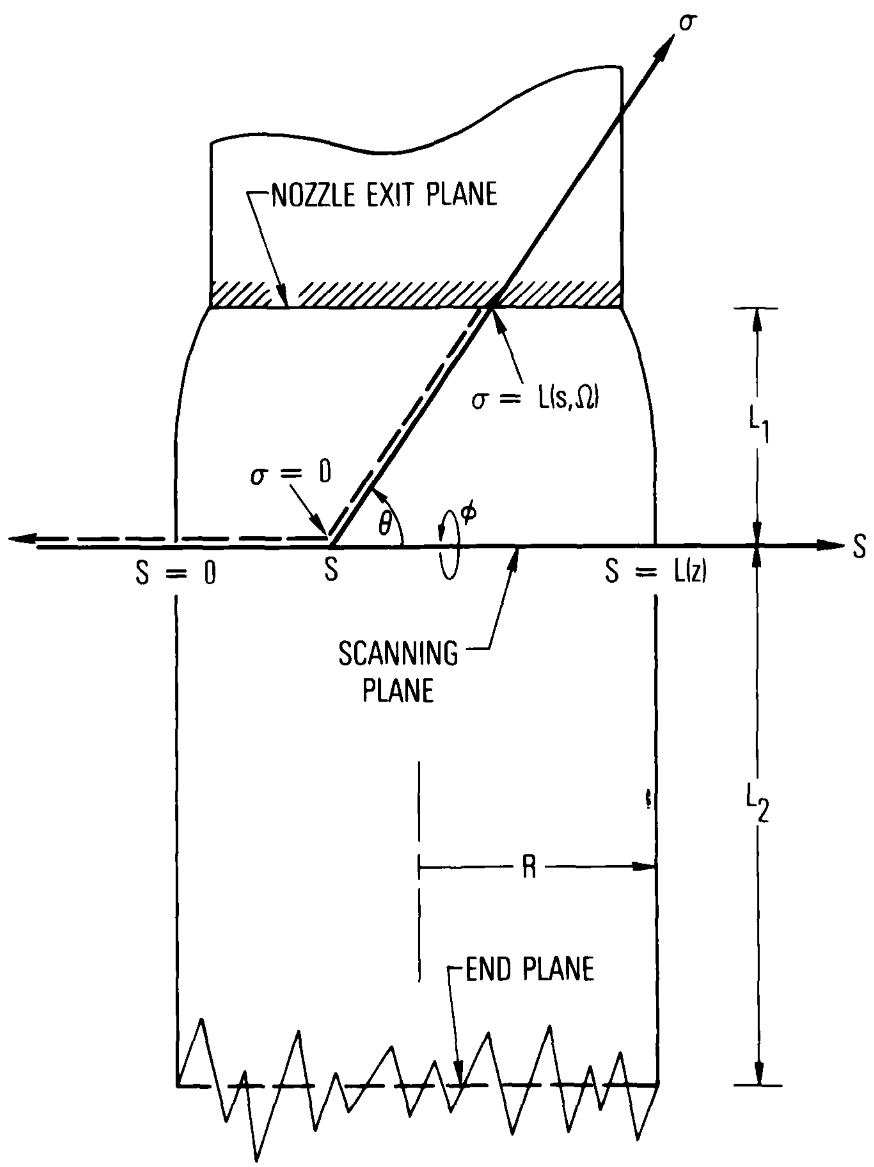


Fig. 1. Single-Scattering Plume Geometry.

It is described by the value of s where it branches off the primary LOS and by the scattering angle θ and the azimuthal angle ϕ. The single-scattering approximation includes radiation emitted along the primary LOS and radiation that has been scattered once from the scattering LOS into the primary LOS. If the scattering LOS terminates on the nozzle exit plane, motor radiation scattered into the primary LOS is also included. The exit plane is modeled as a solid disc with uniform temperature and emissivity.

Extinction of external radiation shown through the plume is assumed to be caused by gas absorption, particle absorption and particle outscattering. The single-scattering approximation does not allow inscattering to contribute to extinction calculations.

The structure of the code is described in Section 2, and a brief description of the function of each subprogram is given. Preparation of input data for the code is described in Section 3. An example application for a plume containing H_2O and Al_2O_3 as the gas and particle species, respectively, is given in Section 4. This example is taken from Ref. 1. A listing of the code is given in the Appendix.

2. CODE STRUCTURE

The organization of the code is shown in Fig. 2. EAPROF is the main program. The subroutine INPUT reads all data required for a run and processes it for compatability with the rest of the code. The function ZONEFIT interpolates on input radial profiles and fits the data on a grid of N equal thickness radial zones. The function ANGLFIT interpolates on the input differential scattering cross section and fits the data to the scattering-angle integration grid (also part of input).

With the radial data fitted to a fixed radial grid, further interpolation is performed to fit the data to the primary and scattering lines of sight. These interpolations are performed by subroutines ZLOS and SLOS, respectively.

QTHERM is the main routine for computing the thermal radiation source function along the primary or scattering LOS. This radiation arises from gas and particle emission. The function KDPARAM interpolates for gas band model parameters along a LOS from input tables of these data. PLANCK computes the blackbody function. The remaining functions listed under QTHERM are radiation functions that are variously employed depending on the lineshape and nonuniformity modes selected for the gas radiation band model. They are described in more detail in Refs. 2 and 3.

---

2. S. J. Young, Description and Use of the Plume Radiation Code ATLES, SAMSO-TR-77-100, U.S. Air Force Space Division, El Segundo, Calif., 13 May 1977.

3. S. J. Young, Inversion of Plume Radiance and Absorptance Data for Temperature and Concentration, AFRPL-TR-78-60, U. S. Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, Calif., 29 September 1978.

Subprogram	Function
EAPROF	main program
INPUT ZONEFIT ANGLFIT	data input and preparation
ZLOS SLOS	line-of-sight data fitting
QTHERM KDPARAM PLANCK F YCGL YDRL YLSL G YCGD YMLD YLSD WMIX YMIX	thermal source function routines
QSCAT	scattering source function routine
RADNCE	radiance routine
OUTPUT	output routine
TRNSFR INITIAL STORE	bookkeeping routines

Fig. 2. Program EAPROF and Associated Subprograms.

The single-scattering source function is computed in QSCAT by an integration over all scattering angles θ and azimuthal angles ϕ. Thermal radiation from the nozzle exit plane is also treated here for scattering lines of sight that terminate on this plane.

The thermal source and scattering source functions are integrated over a LOS in subroutine RADNCE. The results are listed by OUTPUT.

The routines TRNSFR, INITIAL and STORE are bookkeeping routines.

3. PREPARATION OF INPUT DATA

A computational run of program EAPROF requires a set of program control cards to specify the mode of computation and to supply input data. Some program control cards simply specify a computation mode, some specify a computation mode and supply data, while others signal the code that blocks of auxiliary data are now to be read in. Each type of control card contains an alphanumeric name in the first ten card columns. These names must be spelled correctly and must be left-justified. If data are specified on a program control card, they must be entered in accordance with the format specification indicated in the detailed description of each card given below. All fields of the program control cards are 10 columns wide. In general, integer and alphanumeric data must be right-justified in their fields. Non-integer numerical data may be entered in either F or E formats (with decimal point and, for the latter, the exponential symbol E). E-formatted data must be right-justified in their field. These same rules apply to data entered on auxiliary card decks. The types of control cards and the data contained on them are illustrated in Fig. 3. A description of each type follows.

1. Title Card - The card name is TITLE. Columns 11-80 of this card may be used for any identification title desired.

2. Calculation Data Card - The card name is CALCDATA. SHAPE (format A10) must be one of the alphanumeric values LORENTZ, DOPPLER, or VOIGT. INHOM (format A10) must have either the value CG (for the Curtis-Godson approximation) or DR(for the derivative approximation). NZONES (format I10) is the number of radial and transverse zones used by the spatial numerical integration routines. The maximum value of NZONES is 50. NSIGMA (format I10) is the number of equal-length segments that a scattering LOS is divided into for numerical integration.

	10	20	30	40	50	60	70	80
TITLE								
CALCDATA	SHAPE	INHOM	NZONES	NSIGMA	SFLAG			
PLMDATA	L1	L2	TN	EN				
SPECIES	GCOL	PCOL						
GPARAM	PRINT							
GDATA	PRINT							
PPARAM	PRINT							
PDATA	PRINT							
GRID	NPHI	PRINT						
RUN								

Fig. 3. EAPROF Program Control Card Formats.

If SFLAG (format I10) has the value 1, full gas-particle calculations are carried out. If it has the value 0 (or blank), particle effects are ignored.

3. Plume Data Card - The card name is PLMDATA.
L1 (format E10) is the distance (cm) from the nozzle exit plane to the observation scanning plane. L2 (format E10) is the distance (cm) from the scanning plane to the end of the plume. TN (format E10) is the temperature (K) of the nozzle exit plane disc, and EN (format E10) is its emissivity.

4. Species Card - The card name is SPECIES. The GDATA card described under card type 6 allows the entry of up to four different gas species. The variable GCOL (format I10) on the SPECIES card selects the desired species by assuming a value of 1 to 4. Similarly, PCOL (format I10) selects one of the three particle species read in by the control card type 8 by assuming a value of 1 to 3.

5. Band Model Parameter Card - The card name is GPARAM. This card calls for the read-in of band model parameters for the gas species of interest. These parameters are listed if the variable PRINT (format A10) has the value PRINT. The card deck structure for the parameters is given in Fig. 4.

6. Gas Data Card - The card name is GDATA. This card calls for the read-in of the radial profiles of gas temperature, pressure and concentration. The required deck structure is shown in Fig. 5. If the variable PRINT (format A10) has the value PRINT, these data are listed.

10	20	30	40	50	60	70	80
GPRMID	ν	$\Delta\nu$	$\bar{\gamma}$	α_1	α_2	α_3	
T(1)	$\bar{k}(1)$	D(1)					
T(2)	$\bar{k}(2)$	D(2)					
⋮	⋮	⋮					
T(40)	$\bar{k}(40)$	D(40)					

All Field formats are E10 or F10 except the GPRMID field which is A10.

GPRMID	Identification name.
ν	Spectral position (cm^{-1}).
$\Delta\nu$	Spectral resolution (cm^{-1}).
$\bar{\gamma}$	Pressure broadening coefficient (cm^{-1}/atm) for nonresonant self broadening at STP.
α_1	Ratio of resonant self broadeining parameter to $\bar{\gamma}$ at STP.
α_2	Ratio of foreign gas broadening parameter to $\bar{\gamma}$ at STP.
α_3	Atomic weight of active gas species (amu).
T(i)	Temperature array (K). The array must be $T(i) = 100i$, $i = 1, 2, \ldots, 40$.
$\bar{k}(i)$	Absorption coefficient for ν, $\Delta\nu$ and T(i) (cm^{-1}/atm).
D(i)	Line density parameter for ν, $\Delta\nu$ and T(i) (lines/cm^{-1}). Note, $D = 1/\bar{\delta}$.

Fig. 4. **Input Card File Structure for Band Model Parameters.**

10	20	30	40	50	60	70	80
GDTAID	N	R	GNAME1	GNAME2	GNAME3	GNAME4	
r(1)	p(1)	T(1)	$c_1(1)$	$c_2(1)$	$c_3(1)$	$c_4(1)$	
r(2)	p(2)	T(2)	$c_1(2)$	$c_2(2)$	$c_3(2)$	$c_4(2)$	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	
r(N)	p(N)	T(N)	$c_1(N)$	$c_2(N)$	$c_3(N)$	$c_4(N)$	

All field formats are E10 or F10 except the GDTAID, GNAME1, GNAME2, GNAME3 and GNAME4 fields which are A10 and the N field which is I10.

GDTAID	Gas data identification name.
N	Number of radial points ($N \leq 201$).
R	Source radius (cm).
GNAME1 → GNAME4	Gas species identification names.
r(i)	Radial positions (cm). $0 = r(1) < \ldots < r(N) = R$.
T(i)	Temperature (K) at r(i).
$c_j(i)$	Concentration (mole fraction) of species j ($j = 1, \ldots, 4$) at r(i).

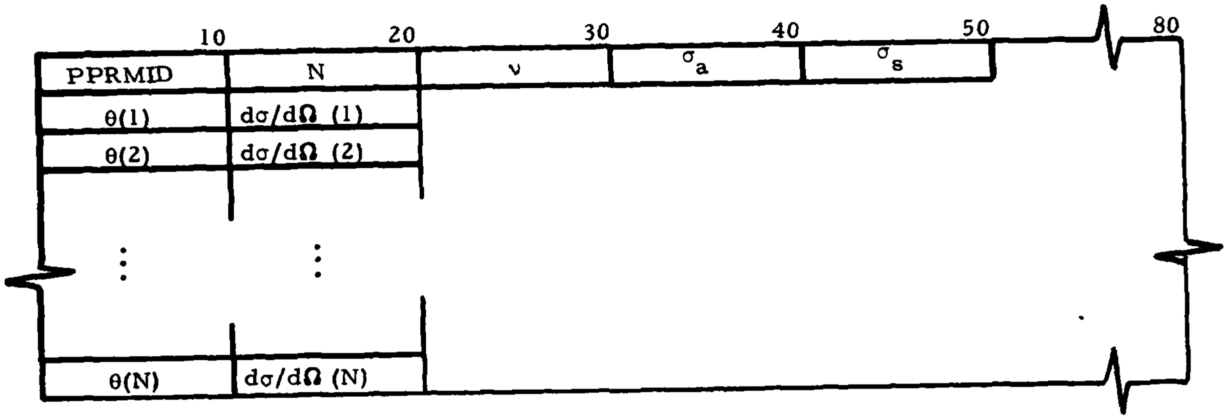
Fig. 5. Input Card File Structure for Radial Gas Data.

7. Particle Parameters Card - The card name is PPARAM. This card calls for the read-in of particle scattering data. The required deck structure is shown in Fig. 6. If the variable PRINT (format A10) has the value PRINT, these data are listed.

8. Particle Data Card - The card name is PDATA. This card calls for the read-in of the radial profiles of particle temperature and number density. The required deck structure is shown in Fig. 7. If the variable PRINT (format A10) has the value PRINT, these data are listed.

9. Angle Integration Grid - The card name is GRID. The card supplies and calls for the read in of data defining the grid over which angle integrations are carried out. NPHI (format I10) is the number of intervals over which the 360° azimuthal integration is carried out. The scattering angle integration over 180° is carried out on the grid defined in Fig. 8. If the variable PRINT (format A10) on the GRID card has the value PRINT, the scattering angle grid is listed.

10. Execution Card - The card name is RUN. When this card is encountered, computations are begun using the data entered up to that point, and an output listing of the results is made. When the computation and results listing are completed, the program continues to read program control cards until a new RUN card is encountered. A new computation is then begun for all of the conditions and data of the first run except those which have been changed by the intervening program control cards and auxiliary data decks. This process is repeated until an end-of-file card is encountered. With this feature, a large number of related runs can be made with one job submission.



All field formats are E10 or F10 except the PPRMID field which is A10 and the N field which is I10.

PPRMID	Particle parameters identification name.
N	Number of scattering angles ($N \le 181$).
ν	Spectral position (cm^{-1}).
σ_a	Absorption cross section (cm^2).
σ_s	Total scattering cross section (cm^2).
$\theta(i)$	Scattering angle array (deg). $0 \le \theta(1) < \theta(2) < \ldots < \theta(N) \le 180^\circ$.
$d\sigma/d\Omega(i)$	Differential scattering cross section for $\theta(i)$ (cm^2/sr).

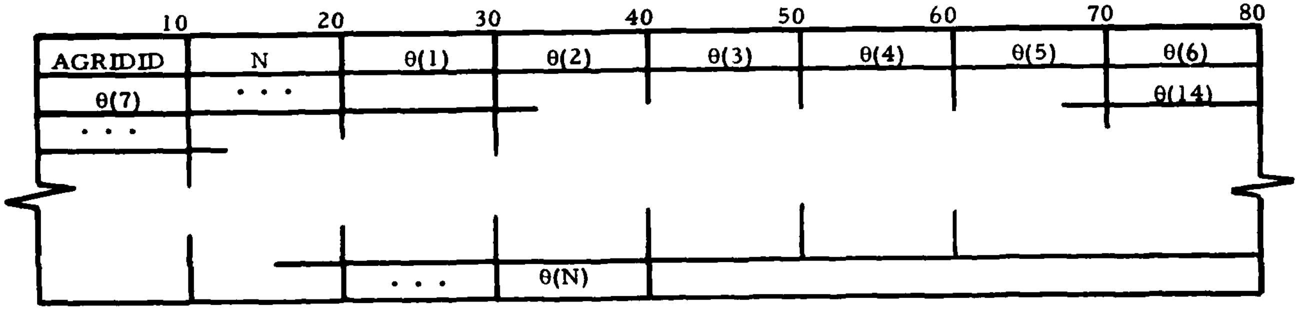
Fig. 6. Input Card File Structure for Particle Scattering Parameters.

10	20	30	40	50	60	70	80
PDTAID	N	R	PNAME1	PNAME2	PNAME3		
r(1)	$T_1(1)$	$c_1(1)$	$T_2(1)$	$c_2(1)$	$T_3(1)$	$c_3(1)$	
r(2)	$T_1(2)$	$c_1(2)$	$T_2(2)$	$c_2(2)$	$T_3(2)$	$c_3(2)$	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	
r(N)	$T_1(N)$	$c_1(N)$	$T_2(N)$	$c_2(N)$	$T_3(N)$	$c_3(N)$	

All field formats are F10 or E10 except the PDTAID and PNAME1 through PNAME3 fields which are A10, and the N field which is I10.

PDTAID	Particle data identification name.
N	Number of radial points ($N \leq 201$).
R	Source radius (cm).
PNAME1 → PNAME3	Particle species identification names.
r(i)	Radial positions (cm). $0 \leq r(1) < \ldots < r(N) \leq R$.
$T_j(i)$	Temperature (K) of species j ($j = 1, \ldots, 4$) at r(i). Note, if $T_j(1) < 0$, the particle temperature profile for the jth species is set equal to the gas temperature profile.
$c_j(i)$	Concentration (particles/cm^3) of species j ($j = 1, \ldots, 4$) at r(i).

Fig. 7. Input Card File Structure for Radial Particle Data.



All field formats are E10 or F10 except the AGRIDID field which is A10 and the N field which is I10.

AGRIDID	Angle grid identification name.
N	Number of scattering angles ($N \le 37$).
$\theta(i)$	Scattering angle array (deg). $0 \le \theta(1) < \theta(2) < \ldots < \theta(N) \le 180^\circ$.

Fig. 8. Input Card File Structure for Scattering Angle Integration Grid.

Other than the requirement that all required data be specified before a RUN card is encountered and that auxiliary data immediately follow the control card that calls for them, the program control cards may be arranged in any order.

Great care should be taken in the preparation of input data since very few checks of data consistency and setting of default values are provided. A general feature of data preparation is that, if particular data on a card are not required, they need not be specified. If none of the data on a control card is needed, that card need not be included.

4. EXAMPLE APPLICATION

An example application of EAPROF is made here for a plume containing H_2O as the active gas species and Al_2O_3 as the particle species. A discussion of this plume model is made in Ref. 1. The radial gas data are shown in Fig. 9. The particle radial profile is flat with the loading value $N_p = 10^5/cm^3$. The H_2O band model parameters are the NERD wideband parameters of Fig. 10 (Ref. 3) and are appropriate to a band center $\sim 3985\ cm^{-1}$ and a bandpass of $\sim 300\ cm^{-1}$. The nonresonant, self-broadening parameter is $\gamma_0 = .07394\ cm^{-1}/atm$. The efficiency for resonant self-broadening is 6.53, and the efficiency for foreign gas broadening is 1.00.

Particle scattering cross sections were computed using Mie theory, the particle size distribution of Fig. 11 and the indexes of refraction $m = 2.51 - i0.0018$, $2.51 - i0.01$ and $2.51 - i0.05$. The first listed value is the accepted value for pure Al_2O_3. The stuff of real plumes is not likely to be so pure. The two other values are simply arbitrary values selected to parametrically study the problem. The value $m = 2.51 - i0.01$ is used in this example. The results for the scattering cross sections are shown in Fig. 12.

Azimuthal integration was performed with a 16-point grid. The scattering angle integration grid and the manner in which it covers the weighting function $\sin\theta\ p(\theta)$ of the scattering source function integral [$p(\theta)$ is a scaled value of $d\sigma/d\Omega$] are illustrated in Fig. 13.

Calculations were made for the Lorentz line shape and the CG approximation. The number of radial/transverse zones was 10, and scattering lines of sight were also divided into 10 segments for numerical integration. The distance from the exit plane to the observation plane was taken as 3 cm, and the distance from the observation plane to the end of the plume was fixed at 15 cm. The exit plane was modeled as a flat disc with uniform temperature $T = 800$ K and emissivity $\epsilon = 0.75$.

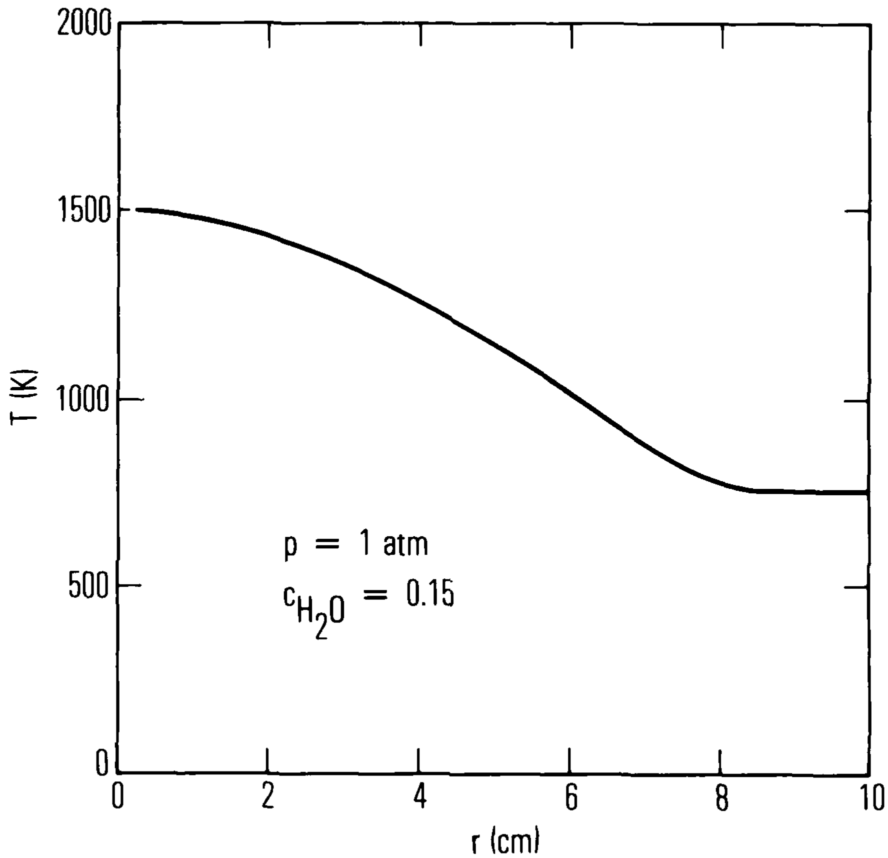


Fig. 9. Radial Gas Data.

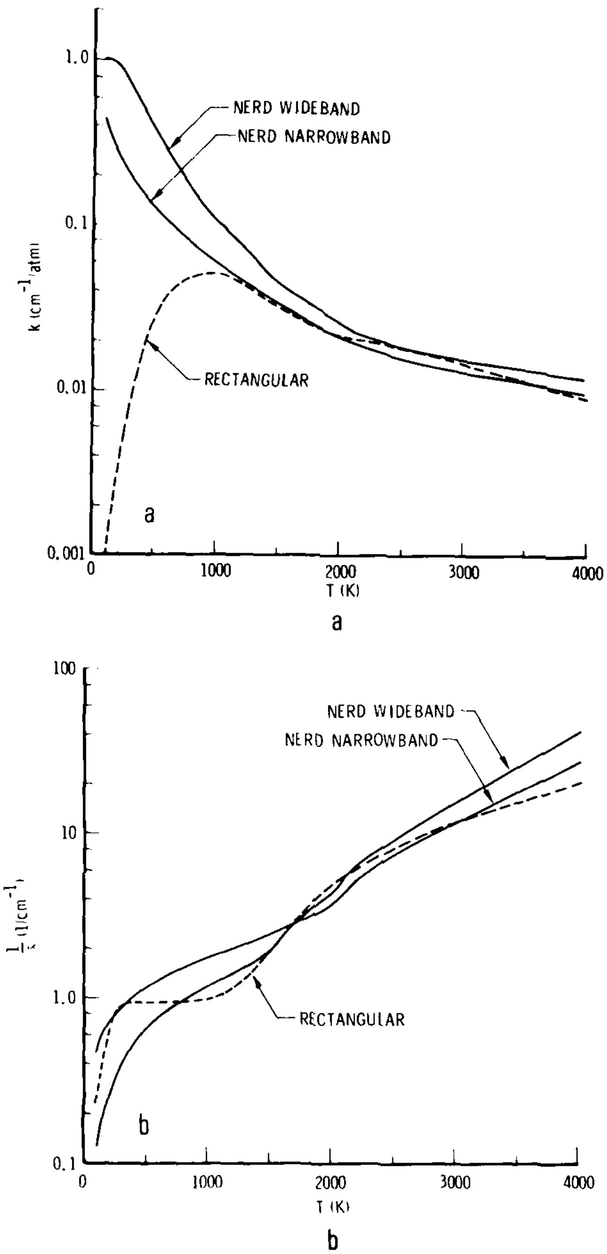


Fig. 10. H_2O Band Model Parameters. a) Absorption Coefficient; b) *Line Density.*

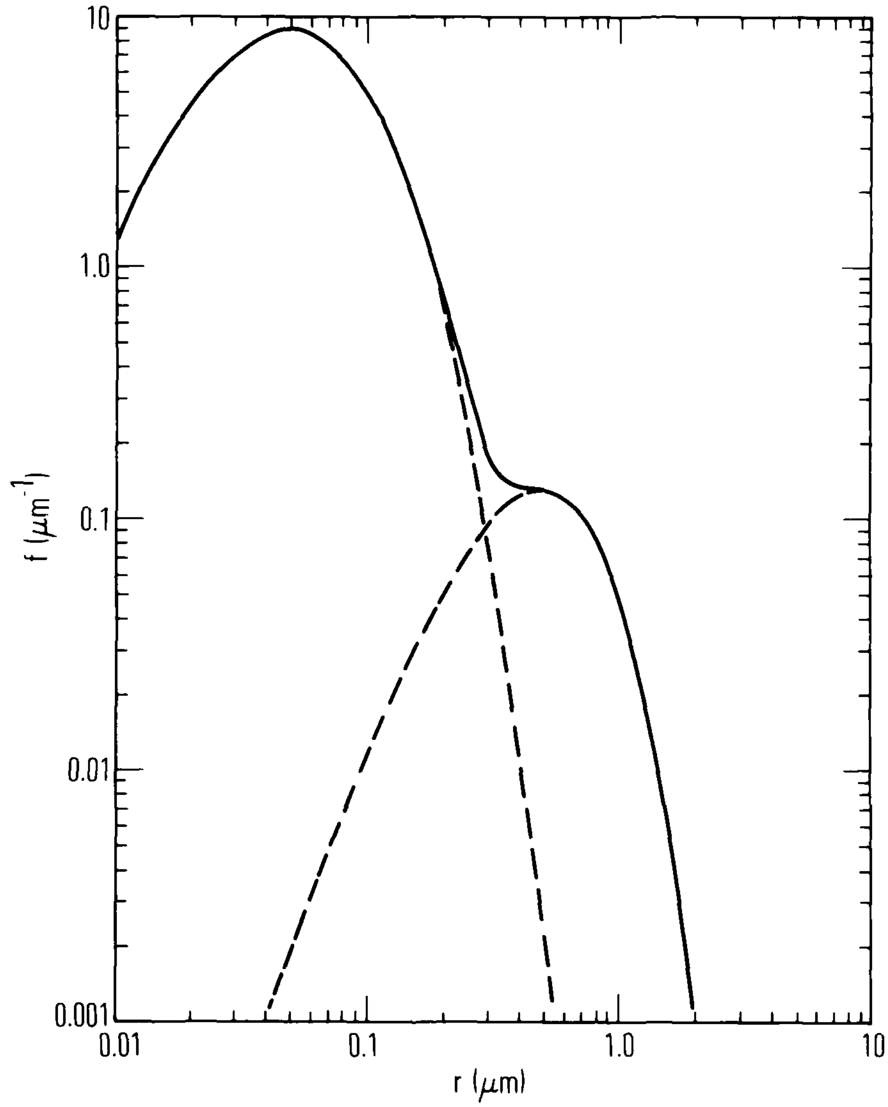


Fig. 11. Al_2O_3 Size Distribution.

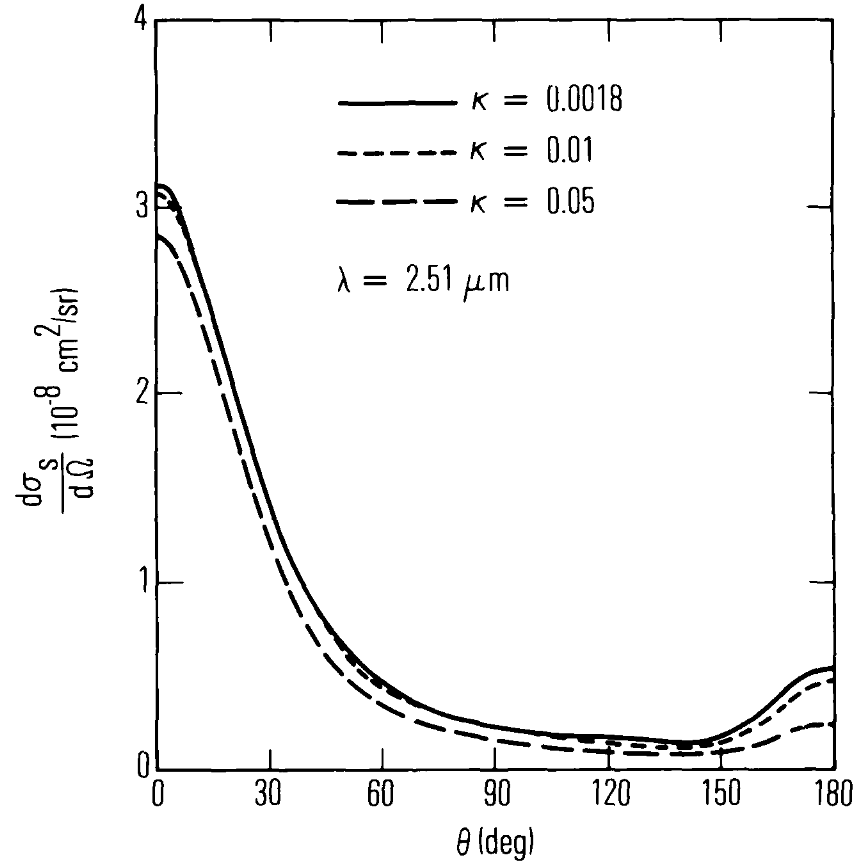


Fig. 12. Differential Scattering Cross Sections for Al_2O_3.

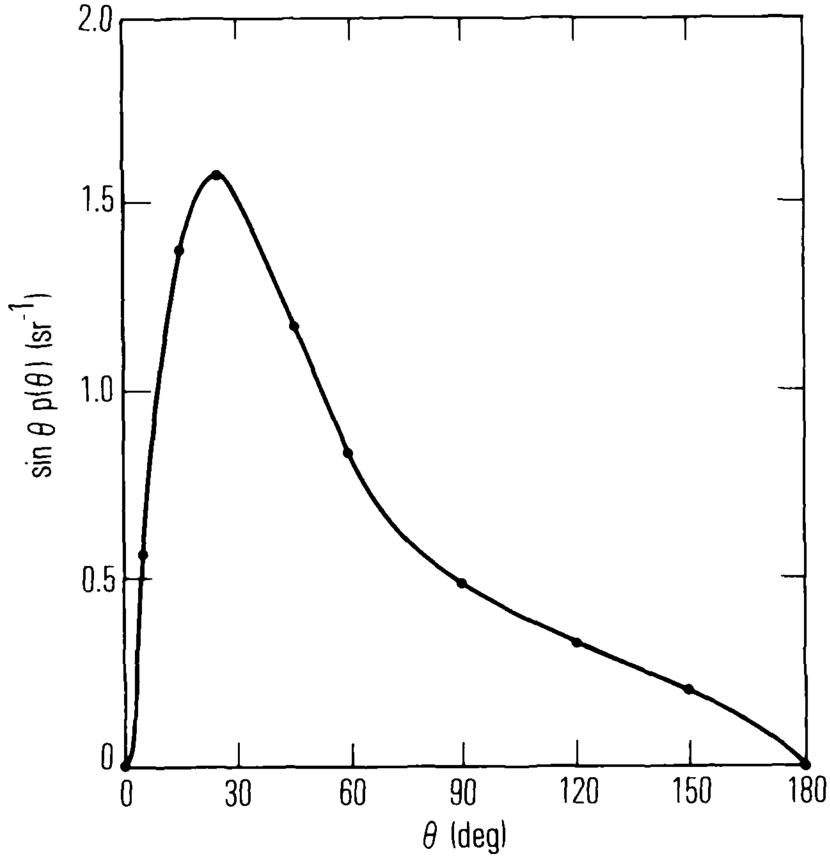


Fig. 13. Coverage of the Scattering Integral Weighting Function by the 11-Point Scattering Angle Grid.

A listing of the input data for these calculation conditions is shown in Fig. 14. The resulting output is shown in Figs. 15 and 16. Figure 16 also shows the results for computations assuming gas-only and particle only conditions. The gas-only results were obtained by changing the SFLAG value on the CALCDATA card from 1 to 0. The particle-only results were obtained by setting SFLAG back to 1 and substituting a band model parameter card deck in which the $\bar{k}$ values for all temperature were set to $\bar{k} = 10^{-40} cm^{-1}/atm$.

```
TITLE      EAPROF EXAMPLE RUN -- AL2O3/H2O PLUME
CALCDATA      LORENTZ        CG         10         13          1
PLMDATA            3.        15.        800.       0.75
SPECIES            1          1
GPARAM
  NERDH2JW      3985.0      300.      J.07394      6.53       1.00       10.
     100.  .4262E+00  .1242E+00
     200.  .2688E+00  .2722E+00
     300.  .1972E+00  .4058E+00
     400.  .1614E+00  .5306E+00
     500.  .1256E+00  .6658E+00
     600.  .1077E+00  .7773E+00
     700.  .8995E-01  .8926E+00
     800.  .7672E-01  .9990E+00
     900.  .6836E-01  .1096E+01
    1000.  .6000E-01  .1189E+01
    1100.  .5466E-01  .1318E+01
    1200.  .4920E-01  .1452E+01
    1300.  .4380E-01  .1592E+01
    1400.  .3839E-01  .1738E+01
    1500.  .3299E-01  .1893E+01
    1600.  .3057E-01  .2359E+01
    1700.  .2815E-01  .2828E+01
    1800.  .2573E-01  .3313E+01
    1900.  .2331E-01  .3822E+01
    2000.  .2089E-01  .4363E+01
    2100.  .1980E-01  .5327E+01
    2200.  .1871E-01  .6312E+01
    2300.  .1762E-01  .7323E+01
    2400.  .1652E-01  .8362E+01
    2500.  .1543E-01  .9435E+01
    2600.  .1499E-01  .1057E+02
    2700.  .1455E-01  .1169E+02
    2800.  .1411E-01  .1283E+02
    2900.  .1367E-01  .1397E+02
    3000.  .1323E-01  .1511E+02
    3100.  .1284E-01  .1665E+02
    3200.  .1246E-01  .1836E+02
    3300.  .1209E-01  .2027E+02
    3400.  .1174E-01  .2241E+02
    3500.  .1142E-01  .2479E+02
    3600.  .1107E-01  .2745E+02
    3700.  .1075E-01  .3043E+02
    3800.  .1044E-01  .3378E+02
    3900.  .1015E-01  .3753E+02
    4000.  .9861E-02  .4175E+02
GDATA
    RATES2           11         10.        H2O        CO2         CO
        0.          1.0       1500.       0.15       0.15       0.35
        1.          1.0       1475.       0.15       0.15       0.35
        2.          1.0       1435.       0.15       0.15       0.35
        3.          1.0       1365.       0.15       0.15       0.35
        4.          1.0       1280.       0.15       0.15       0.35
        5.          1.0       1165.       0.15       0.15       0.35
        6.          1.0       1035.       0.15       0.15       0.35
        7.          1.0        880.       0.15       0.15       0.35
        8.          1.0        765.       0.15       0.15       0.35
        9.          1.0        750.       0.15       0.15       0.35
       10.          1.0        750.       0.15       0.15       0.35
PPARAM
AO-K-2.5-2           21       3985.    3.20E-9    5.58E-8
        1.     3.36E-8
        5.     2.98E-8
       10.     2.75E-8
       15.     2.42E-8
       20.     2.05E-8
       30.     1.39E-8
       40.     9.14E-9
       50.     6.18E-9
       60.     4.33E-9
       70.     3.29E-9
       80.     2.59E-9
       90.     2.15E-9
      100.     1.97E-9
      110.     1.71E-9
      120.     1.62E-9
      130.     1.53E-9
      140.     1.47E-9
      150.     1.70E-9
      160.     2.62E-9
      170.     4.06E-9
      180.     4.87E-9
PDATA
    RATES2/7          2         10.      AL2O3
        0.          -1.        1.E5
       10.          -1.        1.E5
GRID                 16
AL2O3-K2.5           11         -5.         5.        15.        25.        35.        45.
       60.          90.        120.       150.       180.
RUN
```

Fig. 14. Input Data Listing.

**************************************SUMMARY LISTING OF INPUT DATA**************************

JOB TITLE	EAPROF EXAMPLE RUN -- AL2O3/H2O PLUME
SOURCE RADIUS(CM)	1.000E+01
LINESHAPE	LORENTZ
INHOMOGENEITY APPROXIMATION	CG
NUMBER OF ZONES	10
GAS SPECIES	H2O
BAND MODEL PARAMETER IDNAME	NERDH2OW
GAS DATA IDNAME	BATES2
PARTICLE SPECIES	AL2O3
SCATTERING PARAMETER IDNAME	AO-K-2.5-2
PARTICLE DATA IDNAME	BATES2/7
SCATTERING GRID IDNAME	AL2O3-K2.5
NUMBER OF SCATTERING ANGLES	11
NUMBER OF AZIMUTHAL ANGLES	16
NUMBER OF SIGMA-AXIS INTERVALS	10
DISTANCE TO NOZZLE PLANE(CM)	3.000E+00
DISTANCE TO END PLANE(CM)	1.500E+01
NOZZLE TEMPERATURE(DEGK)	8.000E+02
NOZZLE EMISSIVITY	7.500E-01
SCATTERING FLAG	1

E/A PROFILE RESULTS***************************

INDEX	N(W/CM2*SR*CM-1)	N(W/CM2*SR*MICRON)	EXTINCTION	TRANSMITTANCE
1	5.916E-05	9.395E-02	2.109E-01	7.891E-01
2	5.730E-05	9.100E-02	2.107E-01	7.893E-01
3	5.218E-05	8.286E-02	2.099E-01	7.901E-01
4	4.415E-05	7.011E-02	2.082E-01	7.918E-01
5	3.400E-05	5.400E-02	2.053E-01	7.947E-01
6	2.311E-05	3.670E-02	2.006E-01	7.994E-01
7	1.366E-05	2.169E-02	1.939E-01	8.061E-01
8	7.370E-06	1.170E-02	1.829E-01	8.171E-01
9	4.708E-06	7.476E-03	1.625E-01	8.375E-01
10	3.454E-06	5.485E-03	1.259E-01	8.741E-01
11	0.	0.	0.	1.000E+00

Fig. 15. Output Listing.

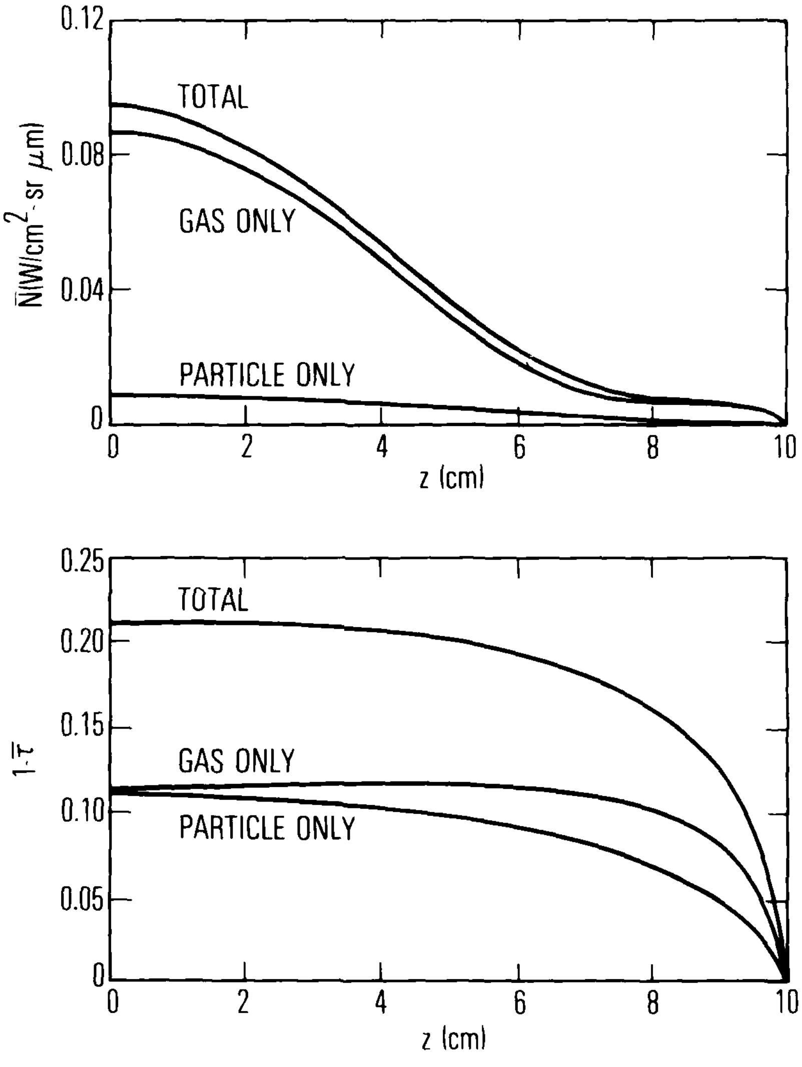


Fig. 16. Transverse Emission and Extinction Profiles.

APPENDIX

LISTING OF PROGRAM EAPROF

```
          PROGRAM EAPROF(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
     C
     C         COMPUTE TRANSVERSE EMISSION AND EXTINCTION PROFILES FOR AN
     C         AXISYMMETRIC, AXIALLY UNIFORM, CYLINDRICAL PLUME FROM INPUT
     C         RADIAL PROFILES OF GAS TEMPERATURE, PRESSURE AND CONCENTRATION
     C         AND PARTICLE TEMPERATURE AND NUMBER DENSITY.  GAS AND PARTICLE
     C         RADIATION ARE COUPLED BY USE OF A SINGLE-SCATTERING RADIATION
     C         BAND MODEL.
     C
          DIMENSION RAD(51),ABS(51)
          INTEGER SFLAG
          COMMON/OUTPT/RAD,ABS
     C
     C READ INPUT DATA
        1 CALL INPUT(NZONES,SFLAG)
     C LOOP OVER TRANSVERSE POSITIONS
 4        DO 3 J=1,NZONES
     C COMPUTE THERMAL SOURCE FUNCTION AND TRANSMITTANCE COMPONENTS
 6        CALL ZLOS(J,NLOS)
10        CALL TRNSFR
11        CALL INITIAL(0,NLOS)
13        CALL QTHERM(1,SFLAG)
15        CALL STORE
     C COMPUTE SCATTERING SOURCE FUNCTION
16        IF(SFLAG.NE.1) GO TO 2
20        CALL INITIAL(1,NLOS)
22        CALL QSCAT(J)
     C COMPUTE LINE-OF-SIGHT RADIANCE AND EXTINCTANCE
24      2 CALL RESTORE
25        CALL RADNCE(SFLAG,RTN1,RTN2)
30        RAD(J)=RTN1
32      3 ABS(J)=RTN2
37        RAD(NZONES+1)=0.
37        ABS(NZONES+1)=0.
     C PRINT RESULTS
40        CALL OUTPUT
41        GO TO 1
42        END
```

```
      SUBROUTINE INPUT(MZONES,SFLAG)
C
C         READ, PREPARE, AND STORE ALL DATA REQUIRED FOR A
C         COMPUTATIONAL RUN OF PROGRAM EAPROF.
C
      DIMENSION W(7),TITLE(7),GNAME(4),PNAME(3),TYPE(10)
      DIMENSION TPARAM(40),DPARAM(40)
      DIMENSION RGX(201),PX(201),TGX(201),CGX(4,201)
      DIMENSION ANGX(181),DSX(181)
      DIMENSION RPX(201),TPX(4,201),CPX(4,201)
      DIMENSION ANG(37),PHASE(37)
      DIMENSION CX(201),TX(201)
      DIMENSION R(51),P(51),TG(51),CG(51),TP(51),CP(51)
      INTEGER   PCOL,GCOL,SFLAG
      REAL      KPARAM(40),INHOM
      COMMON/DATA1/NZONES,RADIUS,DELR,NSIGMA
      COMMON/DATA2/SHAPE,INHOM,WN
      COMMON/DATA3/TPARAM,KPARAM,DPARAM,WNG,WSTP,A1,A2,A3
      COMMON/DATA4/ANG,PHASE,NSCAT,NPHI,SIGA,SIGS
      COMMON/DATA5/P1,P2,EN,TN
      COMMON/FTCPR/R,P,TG,CG,TP,CP,NNZONE
      DATA TYPE( 1)/10HTITLE      /
      DATA TYPE( 2)/10HCALCDATA   /
      DATA TYPE( 3)/10HPLMDATA    /
      DATA TYPE( 4)/10HSPECIES    /
      DATA TYPE( 5)/10HGPARAM     /
      DATA TYPE( 6)/10HGDATA      /
      DATA TYPE( 7)/10HPPARAM     /
      DATA TYPE( 8)/10HPDATA      /
      DATA TYPE( 9)/10HGRID       /
      DATA TYPE(10)/10HRUN        /
      DATA PRINT/10H     PRINT/
C
C READ CARD TYPE AND ROUTE TO APPROPRIATE DECODING AND DATA
C READ-IN ROUTINE
    1 READ(5,100) CARD,(W(I),I=1,7)
 14   IF(EOF,5) 2,3
 20 2 STOP
 22 3 DO 4 I=1,10
 30   IF(CARD.EQ.TYPE(I)) GO TO 5
 32 4 CONTINUE
 34   WRITE(6,1000) CARD
 41   STOP
 44 5 GO TO(6,8,9,10,11,14,17,20,23,25),I
C READ TITLE
 62 6 DO 7 I=1,7
 67 7 TITLE(I)=W(I)
 71   GO TO 1
C READ CALCULATION DATA
 71 8 SHAPE=W(1)
 72   INHOM=W(2)
 74   DECODE(30,101,W(3)) NZONES,NSIGMA,SFLAG
114   MZONES=NZONES
114   NNZONE=NZONES+1
115   GO TO 1
C READ PLUME DATA
```

```
116       9 DECODE(40,102,W(1)) P1,P2,TN,EN
135         GO TO 1
        C READ SPECIES COLUMN DATA
137      10 DECODE(20,101,W(1)) GCOL,PCOL
152         GO TO 1
        C READ BAND MODEL PARAMETERS
154      11 READ(5,200) GPRMID,WNG,DELWN,WSTP,A1,A2,A3
176         WN=WNG
200         DO 12 I=1,40
203      12 READ(5,202) TPARAM(I),KPARAM(I),DPARAM(I)
223         IF(W(1).NE.PRINT) GO TO 1
225         WRITE(6,300)
230         WRITE(6,301) GPRMID
237         WRITE(6,302) WNG
246         WRITE(6,303) DELWN
255         WRITE(6,304)
262         WRITE(6,305) WSTP
271         WRITE(6,306) A1
300         WRITE(6,307) A2
307         WRITE(6,308) A3
316         WRITE(6,309)
323         DO 13 I=1,40
326      13 WRITE(6,310) I,TPARAM(I),KPARAM(I),DPARAM(I)
350         GO TO 1
        C READ RADIAL GAS DATA
350      14 READ(5,203) GDTAID,NGDTA,RADIUS,(GNAME(I),I=1,4)
364         DO 15 I=1,NGDTA
367      15 READ(5,202) RGX(I),PX(I),TGX(I),(CGX(J,I),J=1,4)
413         PRINT1=W(1)
414         IF(PRINT1.NE.PRINT) GO TO 1
417         WRITE(6,311)
422         WRITE(6,301) GDTAID
431         WRITE(6,312) RADIUS
440         WRITE(6,313) NGDTA
447         WRITE(6,314)
454         WRITE(6,315) (GNAME(I),I=1,4)
463         DO 16 I=1,NGDTA
466      16 WRITE(6,316) I,RGX(I),PX(I),TGX(I),(CGX(J,I),J=1,4)
514         GO TO 1
        C READ PARTICLE SCATTERING DATA
515      17 READ(5,201) PPRMID,NPPRM,WNP,SIGA,SIGS
533         DO 18 I=1,NPPRM
536      18 READ(5,202) ANGX(I),DSX(I)
553         IF(W(1).NE.PRINT) GO TO 1
555         WRITE(6,317)
561         WRITE(6,318) PPRMID
570         WRITE(6,319) WNP
577         WRITE(6,320) NPPRM
606         WRITE(6,321) SIGA
615         WRITE(6,322) SIGS
624         WRITE(6,323)
631         DO 19 I=1,NPPRM
634      19 WRITE(6,324) I,ANGX(I),DSX(I)
653         GO TO 1
        C READ RADIAL PARTICLE DATA
654      20 READ(5,203) PDTAID,NPDTA,RADIUS,(PNAME(I),I=1,3)
670         DO 21 I=1,NPDTA
```

```
673         READ(5,202) RPX(I),TPX(1,I),CPX(1,I),TPX(2,I),CPX(2,I),
           X TPX(3,I),CPX(3,I)
727      21 CONTINUE
731         PRINT2=W(1)
732         IF(PRINT2.NE.PRINT) GO TO 1
735         WRITE(6,325)
740         WRITE(6,301) PDTAID
747         WRITE(6,312) RADIUS
756         WRITE(6,313) NPDTA
765         WRITE(6,326) (PNAME(I),I=1,3)
774         WRITE(6,327)
1001        DO 22 I=1,NPDTA
1004        WRITE(6,316) I,RPX(I),TPX(1,I),CPX(1,I),TPX(2,I),CPX(2,I),
           X TPX(3,I),CPX(3,I)
1042     22 CONTINUE
1044        GO TO 1
      C READ ANGLE INTEGRATION GRID
1045     23 DECODE(10,101,W(1)) NPHI
1056        READ(5,201) AGPDID,NSCAT,(ANG(I),I=1,6)
1071        IF(NSCAT.GT.6) READ(5,202) (ANG(I),I=7,NSCAT)
1106        PRINT3=W(2)
1107        IF(PRINT3.NE.PRINT) GO TO 1
1112        WRITE(6,328)
1115        WRITE(6,329) AGRDID
1124        WRITE(6,330) NSCAT
1133        WRITE(6,331) NPHI
1142        WRITE(6,332)
1147        DO 24 I=1,NSCAT
1152     24 WRITE(6,333) I,ANG(I)
1166        GO TO 1
      C
      C PREPARE DATA
1167     25 DELR=RADIUS/NZONES
      C SET GAS SPECIES AND FIT RADIAL GAS DATA TO RADIAL GRID
1172        DO 26 I=1,NGDTA
1201     26 CX(I)=CGX(GCOL,I)
1203        CALL ZONEFIT(NGDTA, PX,RGX, P,R)
1207        CALL ZONEFIT(NGDTA, CX,RGX,CG,R)
1213        CALL ZONEFIT(NGDTA,TGX,RGX,TG,R)
1217        IF(PRINT1.NE.PRINT) GO TO 28
1223        WRITE(6,334)
1226        WRITE(6,335) GNAME(GCOL)
1236        WRITE(6,336)
1243        DO 27 I=1,NNZONE
1246     27 WRITE(6,316) I,R(I),P(I),TG(I),CG(I)
      C SET PARTICLE SPECIES AND FIT RADIAL PARTICLE DATA TO RADIAL GRID
1273     28 IF(SFLAG.NE.1) GO TO 35
1275        DO 29 I=1,NPDTA
1305        TX(I)=TPX(PCOL,I)
1306     29 CX(I)=CPX(PCOL,I)
1310        CALL ZONEFIT(NPDTA,CX,RPX,CP,R)
1314        CALL ZONEFIT(NPDTA,TX,RPX,TP,R)
1320        IF(TP(1).GT.(.)) GO TO 31
1324        DO 30 I=1,NNZONE
1331     30 TP(I)=TG(I)
1333     31 IF(PRINT2.NE.PRINT) GO TO 33
1335        WRITE(6,337)
```

```
1341          WRITE(6,335) PNAME(PCOL)
1351          WRITE(6,338)
1356          DO 32 I=1,NNZONE
1361       32 WRITE(6,315) I,P(I),TP(I),CP(I)
     C COMPUTE PHASE FUNCTION OVER ANGLE INTEGRATION GRID
1403       33 IF(SFLAG.NE.1) GO TO 35
1405          CALL ANGLFIT(ANGX,DSX,NPPRM)
1407          IF(PRINT3.NE.PRINT) GO TO 35
1413          WRITE(6,339)
1416          WRITE(6,340)
1423          DO 34 I=1,NSCAT
1426       34 WRITE(6,333) I,ANG(I),PHASE(I)
     C
     C SUMMARY DATA PRINTOUT
1445       35 WRITE(6,400)
1451          WRITE(6,401) (TITLE(I),I=1,7)
1460          WRITE(6,402) RADIUS
1467          WRITE(6,403) SHAPE
1476          WRITE(6,404) INHOM
1505          WRITE(6,405) NZONES
1514          WRITE(6,406) GNAME(GCOL)
1524          WRITE(6,407) GPRMID
1533          WRITE(6,408) GDTAID
1542          WRITE(6,409) PNAME(PCOL)
1552          WRITE(6,410) PPRMID
1561          WRITE(6,411) PDTAID
1570          WRITE(6,412) AGRDID
1577          WRITE(6,413) NSCAT
1606          WRITE(6,414) NP4I
1615          WRITE(6,415) NSIGMA
1624          WRITE(6,416) P1
1633          WRITE(6,417) P2
1642          WRITE(6,418) TN
1651          WRITE(6,419) EN
1660          WRITE(6,420) SFLAG
1670          RETURN
     C
      100 FORMAT(8A10)
      101 FORMAT(3I10)
      102 FORMAT(4E10.0)
      200 FORMAT(A10,8E10.0)
      201 FORMAT(A10,I10,7E10.0)
      202 FORMAT(8E10.0)
      203 FORMAT(A10,I10,E10.0,6A10)
      300 FORMAT(1H1,//6X,37(1H*),*BAND MODEL PARAMETER LISTING*,37(1H*)//)
      301 FORMAT(6X,*DATA IDNAME                     *,A10)
      302 FORMAT(6X,*WAVENUMBER(CM-1)                *,1PE10.3)
      303 FORMAT(6X,*SPECTRAL RESOLUTION(CM-1) *,1PE10.3/)
      304 FORMAT(6X,*BROADENING PARAMETERS*)
      305 FORMAT(10X,*STP LORENTZ HALFWIDTH(CM-1/ATM)   *,1PE10.3)
      306 FORMAT(10X,*SELF-BROADENING RATIO             *,1PE10.3)
      307 FORMAT(10X,*FOREIGN-GAS BROADENING RATIO)     *,1PE10.3)
      308 FORMAT(10X,*MOLECULAR WEIGHT(AMU)             *,1PE10.3//)
      309 FORMAT(6X,*INDEX*,3X,*T(DEGK)*,4X,*K(CM-1/ATM)*,6X,*D(1/CM-1)*/)
      310 FORMAT(I9,1P2E13.3,E16.3)
      311 FORMAT(1H1,//6X,39(1H*),*RADIAL GAS DATA LISTING*,40(1H*)//)
      312 FORMAT(6X,*SOURCE RADIUS(CM)                *,1PE10.3)
```

```
313  FORMAT(6X,*NUMBER OF RADIAL POINTS     *,I10//)                    INPUT     230
314  FORMAT(6X,*INDEX*,4X,*R(CM)*,7X,*P(ATM)*,5X,*T(DEGK)*,4X,6(1H*),   INPUT     231
    X *GAS CONCENTRATIONS(MOLE FRACTION)*,6(1H*) )                        INPUT     232
315  FORMAT(42X,4(2X,A10)/)                                               INPUT     233
316  FORMAT(I9,1X,1P7E12.3)                                               INPUT     234
317  FORMAT(1H1,//6X,32(1H*),*PARTICLE SCATTERING PARAMETER LISTING*,    INPUT     235
    X 33(1H*) //)                                                         INPUT     236
318  FORMAT(6X,*DATA IDNAME                          *,A10)              INPUT     237
319  FORMAT(6X,*WAVENUMBER(CM-1)                     *,1PE10.3)          INPUT     238
320  FORMAT(6X,*NUMBER OF ANGLES                     *,I10)              INPUT     239
321  FORMAT(6X,*ABSORPTION CROSS SECTION(CM2)   *,1PE10.3)               INPUT     240
322  FORMAT(6X,*SCATTERING CROSS SECTION(CM2)   *,1PE10.3//)             INPUT     241
323  FORMAT(6X,*INDEX*,4X,*ANGLE(DEG)*,4X,*DSS(CM2/SR)* /)               INPUT     242
324  FORMAT(I9,1P2E15.3)                                                  INPUT     243
325  FORMAT(1H1,//6X,37(1H*),*RADIAL PARTICLE DATA LISTING*,37(1H*)//)   INPUT     244
326  FORMAT(6X,*INDEX*,4X,*R(CM)*,7X,A10,14X,A10,14X,A10)                INPUT     245
327  FORMAT(20X,3(5X,*T(DEGK)*,5X,*C(CM-3)* ) /)                         INPUT     246
328  FORMAT(1H1,//5X,36(1H*),*ANGLE INTEGRATION GRID LISTING*,35(1H*)/)  INPUT     247
329  FORMAT(6X,*DATA IDNAME                          *,A10)              INPUT     248
330  FORMAT(6X,*NUMBER OF SCATTERING ANGLES    *,I10)                    INPUT     249
331  FORMAT(6X,*NUMBER OF AZIMUTHAL ANGLES     *,I10//)                  INPUT     250
332  FORMAT(6X,*INDEX*,3X,*ANGLE(DEG)* /)                                INPUT     251
333  FORMAT(I9,1P2E14.3)                                                  INPUT     252
334  FORMAT(1H1,//6X,37(1H*),*INTERPOLATED RADIAL GAS DATA*,37(1H*)//)   INPUT     253
335  FORMAT(6X,*SPECIES=*,A10 //)                                        INPUT     254
336  FORMAT(6X,*INDEX*,4X,*R(CM)*,7X,*P(ATM)*,5X,*T(DEGK)*,3X,           INPUT     255
    X *C(MOLE FRAC)* /)                                                   INPUT     256
337  FORMAT(1H1,//6X,35(1H*),*INTERPOLATED RADIAL PARTICLE DATA*,        INPUT     257
    X 34(1H*) //)                                                         INPUT     258
338  FORMAT(6X,*INDEX*,4X,*R(CM)*,5X,*T(DEGK)*,5X,*C(CM-3)* /)           INPUT     259
339  FORMAT(1H1,//6X,38(1H*),*SCATTERING PHASE FUNCTION*,35(1H*)  //)    INPUT     260
340  FORMAT(6X,*INDEX*,3X,*ANGLE(DEG)*,3X,*PHASE(SR-1)* /)               INPUT     261
400  FORMAT(1H1,//6X,37(1H*),*SUMMARY LISTING OF INPUT DATA*,37(1H*)//)  INPUT     262
401  FORMAT(6X,*JOB TITLE                            *,7A10)             INPUT     263
402  FORMAT(6X,*SOURCE RADIUS(CM)                    *,1PE10.3)          INPUT     264
403  FORMAT(6X,*LINESHAPE                            *,A10)              INPUT     265
404  FORMAT(6X,*INHOMOGENEITY APPROXIMATION          *,A10)              INPUT     266
405  FORMAT(6X,*NUMBER OF ZONES                      *,I10)              INPUT     267
406  FORMAT(6X,*GAS SPECIES                          *,A10)              INPUT     268
407  FORMAT(6X,*BAND MODEL PARAMETER IDNAME          *,A10)              INPUT     269
408  FORMAT(6X,*GAS DATA IDNAME                      *,A10)              INPUT     270
409  FORMAT(6X,*PARTICLE SPECIES                     *,A10)              INPUT     271
410  FORMAT(6X,*SCATTERING PARAMETER IDNAME          *,A10)              INPUT     272
411  FORMAT(6X,*PARTICLE DATA IDNAME                 *,A10)              INPUT     273
412  FORMAT(6X,*SCATTERING GRID IDNAME               *,A10)              INPUT     274
413  FORMAT(6X,*NUMBER OF SCATTERING ANGLES          *,I10)              INPUT     275
414  FORMAT(6X,*NUMBER OF AZIMUTHAL ANGLES           *,I10)              INPUT     276
415  FORMAT(6X,*NUMBER OF SIGMA-AXIS INTERVALS       *,I10)              INPUT     277
416  FORMAT(6X,*DISTANCE TO NOZZLE PLANE(CM)         *,1PE10.3)          INPUT     278
417  FORMAT(6X,*DISTANCE TO END PLANE(CM)            *,1PE10.3)          INPUT     279
418  FORMAT(6X,*NOZZLE TEMPERATURE(DEGK)             *,1PE10.3)          INPUT     280
419  FORMAT(6X,*NOZZLE EMISSIVITY                    *,1PE10.3)          INPUT     281
420  FORMAT(6X,*SCATTERING FLAG                      *,I10)              INPUT     282
1000 FORMAT(1H1,5H*****,*INVALID DATA CARD,  CARD TYPE=*,A10)            INPUT     283
     END                                                                  INPUT     284
```


1671

```
      SUBROUTINE ZONEFIT(N,F,XF,G,X)
C
C         INTERPOLATE ON THE FUNCTION F DEFINED ON THE GRID XF TO GET
C         THE FUNCTION AT THE NZONES+1 EQUALLY SPACED GRID POINTS OF X
C
      DIMENSION F(301),XF(301),G(51),X(51)
      COMMON/CATA1/NZONES,RADIUS,DELR,IIIII
C
      DO 3 I=1,NZONES
      X(I)=(I-1)*DELR
      DO 1 J=1,N
      IF(X(I).LT.XF(J)) GO TO 2
    1 CONTINUE
    2 K=J-1
    3 G(I)=F(K)+(F(K+1)-F(K))*(X(I)-XF(K))/(XF(K+1)-XF(K))
      X(NZONES+1)=RADIUS
      G(NZONES+1)=F(N)
      RETURN
      END
```

```
              SUBROUTINE ANGLFIT(ANGT,DSS,N)
      C
      C           INTERPOLATE ON PARTICLE SCATTERING PARAMETER TABLE TO GET
      C           PHASE FUNCTION FOR ARRAY OF INTEGRATION SCATTERING ANGLES
      C
              DIMENSION ANGT(181),DSS(181),ANG(37),PHASE(37)
              COMMON/DATA4/ANG,PHASE,NSCAT,IIIII,SA,SS
      C
              DO 5 I=1,NSCAT
              AI=ANG(I)
   10         DO 1 J=1,N
   15         AJ=ANGT(J)
   16         IF(AJ.GT.AI) GO TO 2
   21       1 CONTINUE
   23         J=N
   24       2 IF(J.EQ.2) GO TO 3
   27         A1=ANGT(J-2)
   30         A2=ANGT(J-1)
   31         A3=ANGT(J)
   32         F1=DSS(J-2)
   34         F2=DSS(J-1)
   35         F3=DSS(J)
   37         GO TO 4
   37       3 A1=-ANGT(2)
   40         A2=0.
   41         A3=-A1
   42         F1=DSS(2)
   44         F2=DSS(1)
   45         F3=F1
   56       4 D=(A2-A1)*(A3-A2)*(A3-A1)
   60         A=((F1-F2)*(A3-A2)-(F2-F3)*(A2-A1))/D
   64         B=((F3-F2)*(A2-A1)**2-(F1-F2)*(A3-A2)**2)/D
   71       5 PHASE(I)=12.56637*(A*(AI-A2)**2+B*(AI-A2)+F2)/SS
  103         RETURN
  104         END
```

```
      SUBROUTINE ZLOS(J,NNLOS)
C
C         OBTAIN PTC VARIATION OVER THE PRIMARY LOS AT TRANSVERSE
C         POSITION J
C
      DIMENSION RR(51),PR(51),TGR(51),CGR(51),TPR(51),CPR(51)
      DIMENSION S(103),P(103),TG(103),CG(103),TP(103),CP(103)
      COMMON/PTCRR/RR,PR,TGR,CGR,TPR,CPR,NNZONE
      COMMON/PTCPF/S,P,TG,CG,TP,CP,NLOS
C
      NLOS=2*(NNZONE-J) +1
 6    NNLOS=NLOS
 7    NMID=NNZONE+1-J
10    DO 3 N=1,NLOS
12    IF(N.LE.NMID) GO TO 1
14    I=2*(J-1)-(NNZONE-1)+N
17    SIGN=1.
21    GO TO 2
22  1 I=NNZONE+1-N
24    SIGN=-1
31  2 DELR=RR(2)-RR(1)
32    Q1=(NNZONE-1)**2-(J-1)**2
36    Q2=(I-1)**2-(J-1)**2
41    S(N)=DELR*(SQRT(Q1)+SIGN*SQRT(Q2))
52    P(N) = PR(I)
54    TG(N)= TGR(I)
57    CG(N)= CGR(I)
62    TP(N)= TPR(I)
70  3 CP(N)= CPR(I)
75    RETURN
75    END
```

```
              SUBROUTINE TRNSFR
       C
       C          TRANSFER PTC VARIATION ALONG PRIMARY LOS INTO COMMON STORAGE
       C          LOCATION FOR SCATTERING LOS
       C
              DIMENSION SP(103),PP(103),TGP(103),CGP(103),TPP(103),CPP(103)
              DIMENSION SS(103),PS(103),TGS(103),CGS(103),TPS(103),CPS(103)
              COMMON/PTCPP/SP,PP,TGP,CGP,TPP,CPP,NP
              COMMON/PTCSS/SS,PS,TGS,CGS,TPS,CPS,NS
       C
              DO 1 I=1,NP
 10           SS(I)=SP(I)
 11           PS(I)=PP(I)
 13           TGS(I)=TGP(I)
 14           CGS(I)=CGP(I)
 15           TPS(I)=TPP(I)
 16         1 CPS(I)=CPP(I)
 20           NS=NP
 22           RETURN
 22           END
```

```
          SUBROUTINE INITIAL(ISTART,N)
    C
    C         SET UP INITIATING ARRAY S(L,M) FOR INTEGRATION OVER A NEW
    C         (ISTART=0) OR A CONTINUED(ISTART=1) LINE OF SIGHT
    C
          DIMENSION START(103,13),STOP(103,13)
          COMMON/START/START,STOP
    C
          IF(ISTART.EQ.1) GO TO 2
 5        DO 1 M=1,10
15      1 START(1,M)=0.
17        START(1,11)=1.
20        START(1,12)=1.
20        START(1,13)=1.
22        RETURN
22      2 DO 3 L=1,N
24        DO 3 M=1,13
33      3 START(L,M)=STOP(L,M)
41        RETURN
41        END
```

```
          SUBROUTINE QTHERM(LD,SFLAG)
      C
      C        COMPUTE TRANSMITTANCES AND THERMAL SOURCE FUNCTION ALONG AN
      C        ARBITRARY LINE OF SIGHT
      C
          DIMENSION S(103),P(103),TG(103),CG(103),TP(103),CP(103)
          DIMENSION START(103,13),STOP(103,13)
          DIMENSION TA(103),TB(103),TK(103),QT(103),SS(103)
          DIMENSION XXXX1(37),XXXX2(37)
          REAL      LORENTZ,INHOM,K1,K2,KE
          INTEGER   SFLAG
          COMMON/PTCSS/S,P,TG,CG,TP,CP,NLOS
          COMMON/START/START,STOP
          COMMON/DATA2/SHAPE,INHOM,WN
          COMMON/DATA4/XXXX1,XXXX2,IIII1,IIII2,SIGA,SIGS
          COMMON/QTHRM/SS,TA,TB,TK,QT,NNLOS
          DATA LORENTZ/10H   LORENTZ/
          DATA DOPPLER/10H   DOPPLER/
          DATA      DR/10H        DR/
          NNLOS=NLOS
      C
      C INITIATE LOOP OVER LOS
  5       IF(S(NLOS).LE.0.) GO TO 9
  7       SUM1=START(LD,1)
 10       SUM2=START(LD,2)
 12       SUM3=START(LD,3)
 13       SUM4=START(LD,4)
 15       SUM5=START(LD,5)
 16       SUM6=START(LD,6)
 20       SUM7=START(LD,7)
 21       WWD=START(LD, 8)
 23       WWL=START(LD, 9)
 24       W  =START(LD,10)
 26       YD1=START(LD,11)
 27       YL1=START(LD,12)
 31       Y1 =START(LD,13)
 32       S1=0.
 33       SS(1)=0.
 33       P1=P(1)
 35       TG1=TG(1)
 36       CG1=CG(1)
 40       TP1=TP(1)
 41       CP1=CP(1)
 43       CALL KDPARAM(P1,TG1,CG1,K1,D1,WL1,WD1)
 52       TA(1)=EXP(-SUM6)
 55       TB(1)=EXP(-SUM7)
 61       TK(1)=EXP(-W)
 65       QT(1)=CG1*P1*K1*Y1*PLANCK(WN,TG1)
 74       IF(SFLAG.EQ.1) QT(1)=QT(1)+SIGA*CP1*PLANCK(WN,TP1)
      C CONTINUE LOOP OVER LOS
105       DO 8 L=2,NLOS
111       S2=S(L)
112       SS(L)=S2
112       P2=P(L)
114       TG2=TG(L)
115       CG2=CG(L)
117       TP2=TP(L)
```

```
120        CP2=CP(L)                                              QTHERM
122        CALL KOPARAM(P2,TG2,CG2,K2,D2,WL2,WD2)                 QTHERM
133        DS=(S2-S1)/2.                                          QTHERM
      C COMPUTE BAND MODEL GAS TRANSMITTANCE                      QTHERM
136        X1=CG1*P1                                              QTHERM
140        X2=CG2*P2                                              QTHERM
142        SUM1=SUM1+(X1+X2)*DS                                   QTHERM
145        U=SUM1                                                 QTHERM
145        X1=X1*K1                                               QTHERM
147        X2=X2*K2                                               QTHERM
150        SUM2=SUM2+(X1+X2)*DS                                   QTHERM
153        KE=SUM2/SUM1                                           QTHERM
154        X3=X1/D1                                               QTHERM
156        X4=X2/D2                                               QTHERM
160        SUM3=SUM3+(X3+X4)*DS                                   QTHERM
163        DEL=1./D2                                              QTHERM
164        DELE=SUM3/SUM2                                         QTHERM
166        Q=DELE/CEL                                             QTHERM
167        IF(SHAPE.EQ.LORENTZ) GO TO 2                           QTHERM
173        X3=2.12893*X1*WD1*D1                                   QTHERM
176        X4=2.12893*X2*WD2*D2                                   QTHERM
201        SUM4=SUM4+(X3+X4)*DS                                   QTHERM
205        BED=SUM4/SUM2                                          QTHERM
206        XD=U*KE/BED                                            QTHERM
210        BD=X4/X2                                               QTHERM
212        PD=BD/BED                                              QTHERM
214        IF(INHOM.EQ.DR) GO TO 1                                QTHERM
216        YD2=YCGD(XD,PD)                                        QTHERM
220        WWD=BED*G(XD)                                          QTHERM
224        GO TO 2                                                QTHERM
226      1 YD2=YMLD(XD,PD,Q)                                      QTHERM
231        WWD=WWD+(X1*YD1+X2*YD2)*DS                             QTHERM
240      2 IF(SHAPE.NE.DOPPLER) GO TO 3                           QTHERM
242        Y2=YD2                                                 QTHERM
243        W=WWD                                                  QTHERM
245        GO TO 7                                                QTHERM
246      3 X3=6.283185*X1*WL1*D1                                  QTHERM
251        X4=6.283185*X2*WL2*D2                                  QTHERM
254        SUM5=SUM5+(X3+X4)*DS                                   QTHERM
260        BEL=SUM5/SUM2                                          QTHERM
261        XL=U*KE/BEL                                            QTHERM
263        BL=X4/X2                                               QTHERM
265        RL=BL/BEL                                              QTHERM
267        IF(INHOM.EQ.DR) GO TO 4                                QTHERM
271        YL2=YCGL(XL,RL)                                        QTHERM
273        WWL=BEL*F(XL)                                          QTHERM
277        GO TO 5                                                QTHERM
301      4 YL2=YDRL(XL,RL,Q)                                      QTHERM
304        WWL=WWL+(X1*YL1+X2*YL2)*DS                             QTHERM
313      5 IF(SHAPE.NE.LORENTZ) GO TO 6                           QTHERM
315        Y2=YL2                                                 QTHERM
316        W=WWL                                                  QTHERM
320        GO TO 7                                                QTHERM
321      6 WW=U*KE                                                QTHERM
323        W=WMIX(WWD,WWL,WW)                                     QTHERM
326        Y2=YMIX(WWD,WWL,WW,W,YD2,YL2)                          QTHERM
335      7 TK(L)=EXP(-W)                                          QTHERM
```

```
      C COMPUTE PARTICLE TRANSMITTANCES
342         A1=CP1*SIGA
344         A2=CP2*SIGA
345         SUM6=SUM6+(A1+A2)*DS
351         TA(L)=EXP(-SUM6)
355         B1=CP1*SIGS
357         B2=CP2*SIGS
360         SUM7=SUM7+(B1+B2)*DS
364         T3(L)=EXP(-SUM7)
      C COMPUTE THERMAL SOURCE FUNCTION
370         QT(L)=X2*Y2*PLANCK(WN,TG2)
376         IF(SFLAG.EQ.1) QT(L)=QT(L)+A2*PLANCK(WN,TP2)
      C SET UP ENDING ARRAY, STEP VARIABLES, AND CONTINUE LOOP OVER LOS
406         STOP(L, 1)=SUM1
410         STOP(L, 2)=SUM2
412         STOP(L, 3)=SUM3
413         STOP(L, 4)=SUM4
415         STOP(L, 5)=SUM5
416         STOP(L, 6)=SUM6
420         STOP(L, 7)=SUM7
421         STOP(L, 8)=WWD
423         STOP(L, 9)=WWL
424         STOP(L,10)=W
426         STOP(L,11)=YD2
427         STOP(L,12)=YL2
431         STOP(L,13)=Y2
432         S1=S2
433         P1=P2
435         CG1=CG2
436         K1=K2
440         D1=D2
441         WD1=WD2
443         WL1=WL2
444         CP1=CP2
446         YD1=YD2
447         YL1=YL2
453       8 CONTINUE
455         RETURN
      C TRANSFER PATH ARRAY FOR A ZERO LENGTH PATH
456       9 DO 10 L=1,NLOS
463      10 SS(L)=0.
465         RETURN
465         END
```

```
            SUBROUTINE STORE
      C
      C         STORE AND RESTORE TRANSMITTANCES AND THERMAL SOURCE
      C         FUNCTION ALONG PRIMARY LINE OF SIGHT
      C
            DIMENSION S(103),TA(103),TB(103),TK(103),QT(103)
            DIMENSION SS(103),TTA(103),TTB(103),TTK(103),QQT(103)
            COMMON/OTHRM/S,TA,TB,TK,QT,N
      C
            NN=N
   3        DO 1 I=1,N
  11        SS(I)=S(I)
  12        TTA(I)=TA(I)
  14        TTB(I)=TB(I)
  15        TTK(I)=TK(I)
  16      1 QQT(I)=QT(I)
  17        RETURN
  20        ENTRY RESTORE
  25        N=NN
  27        DO 2 I=1,N
  35        S(I)=SS(I)
  36        TA(I)=TTA(I)
  40        TB(I)=TTB(I)
  41        TK(I)=TTK(I)
  42      2 QT(I)=QQT(I)
  43        RETURN
  44        END
```

```
          SUBROUTINE QSCAT(JZ)
      C
      C        COMPUTE SCATTERING SOURCE FUNCTION ALONG PRIMARY LINE
      C        OF SIGHT
      C
          DIMENSION S(103),TP(103),CP(103),QS(103)
          DIMENSION PHASE(37),ANG(37)
          DIMENSION XXXX1(103),XXXX2(103),XXXX3(103),XXXX9(103,13)
          DIMENSION START(103,13)
          COMMON/PTCPP/S,XXXX1,XXXX2,XXXX3,TP,CP,NLOS
          COMMON/DATA2/XXXX4,XXXX5,WN
          COMMON/DATA4/ANG,PHASE,NS,NA,XXXX6,SIGS
          COMMON/DATA5/XXXX7,XXXX8,EN,TN
          COMMON/START/START,XXXX9
          COMMON/QSCAT/QS
      C
      C LOOP OVER PRIMARY LOS
          DO 4 N=1,NLOS
      C INTEGRATE OVER SOLID ANGLE
          CALL SLOS(S(N),JZ,0.,0.,IDUMMY)
  10      CALL QTHERM(N,1)
  12      CALL RADNCE(C,RAD,DUMMY)
  15      F1=6.283185*PHASE(1)*RAD
  17      SUMA=0.
  20      DAA=6.283185/NA
  22      AS2=ANG(2)/57.2957795
  25      DO 1 J=1,NA
  27      AA=(J-1)*DAA
  32      CALL SLOS(S(N),JZ,AS2,AA,IFLAG)
  37      CALL QTHERM(N,1)
  41      CALL RADNCE(C,RAD,ABS)
  44      IF(IFLAG.EQ.1) RAD=RAD+(1.-ABS)*EN*PLANCK(WN,TN)
  56    1 SUMA=SUMA+RAD
  63      F2=SUMA*PHASE(2)*DAA
  65      P1=F1*(1.-COS(AS2))
  71      P2=(F2-F1)/AS2**2
  74      P3=2.*AS2*SIN(AS2)
 100      P4=(AS2**2-2.)*COS(AS2)+2.
 105      SUMS=P1+P2*(P3-P4)
 111      F2=F2*SIN(AS2)
 115      DO 3 I=3,NS
 120      F1=F2
 121      AS1=AS2
 122      AS2=ANG(I)/57.2957795
 124      DAS=(AS2-AS1)/2.
 126      SUMA=0.
 127      DO 2 J=1,NA
 131      AA=(J-1)*DAA
 134      CALL SLOS(S(N),JZ,AS2,AA,IFLAG)
 141      CALL QTHERM(N,1)
 143      CALL RADNCE(C,RAD,ABS)
 146      IF(IFLAG.EQ.1) RAD=RAD+(1.-ABS)*EN*PLANCK(WN,TN)
 160    2 SUMA=SUMA+RAD
 165      F2=SUMA*PHASE(I)*DAA*SIN(AS2)
 172    3 SUMS=SUMS+(F1+F2)*DAS
 200      TK=EXP(-START(N,10))
 205    4 QS(N)=(SIGS*CP(N)/12.56637)*SUMS/TK
```

```
215     RETURN                                          QSCAT    59
215     END                                             QSCAT    60
```

```
      SUBROUTINE SLOS(S0,J,THETA,PHI,IFLAG)
C
C         COMPUTE PTC VARIATION OVER A SCATTERING LOS
C
      DIMENSION RR(51),PR(51),TGR(51),CGR(51),TPR(51),CPR(51)
      DIMENSION S(103),P(103),TG(103),CG(103),TP(103),CP(103)
      COMMON/PTCRR/RR,PR,TGR,CGR,TPR,CPR,NNZONE
      COMMON/PTCSS/S,P,TG,CG,TP,CP,NL
      COMMON/DATA1/NZONES,RADIUS,DELR,NSIGMA
      COMMON/DATA5/P1,P2,XXXX1,XXXX2
C
C
      AS=THETA
      AA=PHI
      SINS=SIN(AS)
      COSS=COS(AS)
      SINA=SIN(AA)
      COSA=COS(AA)
      IFLAG=0
      D=(J-1)*DELR
      SM=2.*SQRT(RADIUS**2-D**2)
      X0=S0-SM/2.
      Y0=D
      IFLAG=0
C
C COMPUTE LENGTH OF LOS AND SET FLAG IF IT INTERSECTS NOZZLE PLANE
      IF(ABS(SINS).LE.0.0001) GO TO 3
      IF(ABS(COSA).LE.0.0001) GO TO 3
      IF(COSA.LT.0.) GO TO 1
      PPF=P1
      IFLAG=1
      GO TO 2
    1 PPP=P2
    2 SIGMA=ABS(PPF/(SINS*COSA))
      RE=SQRT((X0+SIGMA*COSS)**2+(Y0+SIGMA*SINS*SINA)**2)
      IF(RE.GT.1.001*RADIUS) GO TO 3
      SMAX=SIGMA
      GO TO 4
    3 IFLAG=0
      A=1.-(SINS*COSA)**2
      B=2.*(X0*COSS+Y0*SINS*SINA)
      C=RADIUS**2-(X0**2+Y0**2)
      ARG=B**2+4.*A*C
      IF(ARG.LE.0.) ARG=0.
      SMAX=(SQRT(ARG)-B)/(2.*A)
    4 IF(SMAX.LE.0.) RETURN
C
C COMPUTE PTC VARIATION
      NL=NSIGMA+1
      DS=SMAX/NSIGMA
      DO 5 L=1,NL
      S(L)=(L-1)*DS
      X=X0+S(L)*COSS
      Y=Y0+S(L)*SINS*SINA
      R=SQRT(X**2+Y**2)
      I0=1.+R/DELR
      IF(I0.EQ.NNZONE) I0=I0-1
```

```
203          R0=(I0-1)*DELR                                              SLOS      59
207          DR=(R-R0)/DELR                                              SLOS      60
211          P(L)  =  PR(I0)+( PR(I0+1)- PR(I0))*DR                      SLOS      61
214          TG(L)=TGR(I0)+(TGR(I0+1)-TGR(I0))*DR                        SLOS      62
220          CG(L)=CGR(I0)+(CGR(I0+1)-CGR(I0))*DR                        SLOS      63
224          TP(L)=TPR(I0)+(TPR(I0+1)-TPR(I0))*DR                        SLOS      64
231        5 CP(L)=CPR(I0)+(CPR(I0+1)-CPR(I0))*DR                        SLOS      65
240          RETURN                                                      SLOS      66
241          END                                                         SLOS      67
```

```
      SUBROUTINE RADNCE(SFLAG,RAD,ABS)
C
C        COMPUTE LINE OF SIGHT INTEGRAL OVER SOURCE FUNCTIONS
C
      DIMENSION S(103),TA(103),TB(103),TK(103),QT(103),QS(103)
      COMMON/OTHPM/S,TA,TB,TK,QT,NLOS
      COMMON/QSCAT/QS
      INTEGER SFLAG
C
      SUM=0.
      DO 1 L=2,NLOS
      DS=S(L)-S(L-1)
      P1=TA(L-1)*TK(L-1)
      P2=TA(L)*TK(L)
      S1=QT(L-1)
      S2=QT(L)
      IF(SFLAG.NE.1) GO TO 1
      P1=P1*TB(L-1)
      P2=P2*TB(L)
      S1=S1+QS(L-1)
      S2=S2+QS(L)
    1 SUM=SUM+(P1*S1+P2*S2)*DS
      RAD=SUM/2.
      ABS=1.-F2
      RETURN
      END
```

```
             SUBROUTINE OUTPUT
      C
      C          PRINT TRANSVERSE E/A PROFILES
      C
             DIMENSION RAD(51),ABS(51)
             COMMON/OUTPT/RAD,ABS
             COMMON/DATA1/NZONES,XXXX1,XXXX2,IIIII
             COMMON/DATA2/XXXX3,XXXX4,WN
             NN=NZONES+1
      C
   3         WRITE(6,100)
   7         WRITE(6,101)
  13         DO 1 J=1,NN
  16         RAD1=RAD(J)
  17         RAD2=0.0001*RAD1*WN**2
  21         ABS1=ABS(J)
  23         TRNS=1.-ABS1
  25       1 WRITE(6,102) J,RAD1,RAD2,ABS1,TRNS
  45         RETURN
      C
      C
         100 FORMAT(1H1,//6X,42(1H*),*E/A PROFILE RESULTS*,42(1H*) //)
         101 FORMAT(6X,*INDEX*,3X,*N(W/CM2*,9H*SR*CM-1),3X,*N(W/CM2*,
            * 11H*SR*MICRON),3X,*EXTINCTION*,3X,*TRANSMITTANCE* /)
         102 FORMAT(I9,1PE18.3,E20.3,E17.3,E14.3)
  45         END
```

```
      FUNCTION PLANCK(WN,T)
C
C         COMPUTE THE PLANCK RADIATION FUNCTION(W/CM2*SR*CM-1)  FOR
C         WAVENUMBER WN(CM-1) AND TEMPERATURE T(DEGK)
C
      PLANCK=1.191E-12*WN**3/(EXP(1.4388*WN/T)-1.)
      RETURN
      END
```

```
          SUBROUTINE KDPARAM(P,T,C,K,D,WL,WD)
    C
    C         COMPUTE THE BAND MODEL PARAMETERS
    C              K=ABSORPTION COEFFICIENT(CM-1/ATM)
    C              C=EFFECTIVE LINE DENSITY(LINES/CM-1)
    C              WL=FWHM LORENTZ LINE WIDTH(CM-1)
    C              WD=FWHM DOPPLER LINE WIDTH(CM-1)
    C         FROM INPUT P(ATM), T(DEGK), AND C(MOLE FRACTION) DATA.
    C
          DIMENSION TPARAM(40),DPARAM(40)
          REAL      KPARAM(40),K
          COMMON/DATA3/TPARAM,KPARAM,DPARAM,WN,WSTP,A1,A2,A3
    C
    C TEST FOR T OUTSIDE INTERPOLATION RANGE
          TE=100.
12        IF(T.LE. 100.) GO TO 1
14        TE=4000.
15        IF(T.GE.4000.) GO TO 1
17        TE=T
    C
    C INTERPOLATE FOR K AND D
20      1 N=TE/100.
22        IF(N.EQ.40) N=39
25        DELT=(TE-TPARAM(N))/100.
30        K=KPARAM(N)+DELT*(KPARAM(N+1)-KPARAM(N))
34        D=DPARAM(N)+DELT*(DPARAM(N+1)-DPARAM(N))
    C
    C COMPUTE LINE WIDTHS
41        SRT=SQRT(273./TE)
44        WL=P*WSTP*(C*A1*SRT**2+C*SRT+(1.-C)*A2*SRT)
60        WD=3.568176-7*WN*SQRT(TE/A3)
66        RETURN
67        END
```

```
          FUNCTION YCGL(X,R)                                              YCGL     2
C                                                                         YCGL     3
C             EQUIVALENT WIDTH DERIVATIVE FUNCTION FOR A BAND OF LORENTZ  YCGL     4
C             LINES WITH AN EXPONENTIAL-TAILED INVERSE LINE STRENGTH      YCGL     5
C             DISTRIBUTION AND FOR THE CURTIS-GODSON APPROXIMATION        YCGL     6
C                                                                         YCGL     7
          YCGL=1.                                                         YCGL     8
   5      IF (X.EQ.0.) RETURN                                             YCGL     9
   7      Z=3.1415927*X                                                   YCGL    10
  10      XX=SQRT(1.+2.*Z)                                                YCGL    11
  15      YCGL=(2.-R)/XX+(R-1.)*(XX-1.)/Z                                 YCGL    12
  26      RETURN                                                          YCGL    13
  26      END                                                             YCGL    14
```

```
      FUNCTION YDRL(X,R,Q)
C
C     COMPUTE Y(X,R,Q) IN THE DERIVATIVE APPROXIMATION BY
C     INTEGRATION OF Y(X,R,1) OBTAINED FOR A STATISTICAL ARRAY
C     OF LORENTZ LINES WITH AN EXPONENTIAL-TAILED INVERSE LINE
C     STRENGTH DISTRIBUTION AND THE LINDQUIST-SIMMONS APPROXIMATION
C
      DATA F/0.10/
      Z=3.14159265*X
      YDRL=YLSL(Z,R)
      IF(Q.LE.1.) RETURN
      YDRL=YDRL/Q
      IF(Z.GT.0.01) GO TO 1
      YDRL=YDRL+(Q-1.)*(1.-2.*Z/((1.+R)*(1.+Q)))/Q
      RETURN
    1 SUM=Q*(1.-3.02/((1.+R)*(1.+Q)))*(.01)**(1./Q)
      IFLAG=0
      U1=0.01
    2 U2=(SQRT(1.+8.*U1*(1.+2.*U1)/F)-1.)/4.
      IF(U2.LT.Z) GO TO 3
      U2=Z
      IFLAG=1
    3 B=2./(U2-U1)
      A=1.-U2*B
      UU1=(-A+0.57735027)/B
      UU2=(-A-0.57735027)/B
      QQ=(1./Q)-1.
      P1=YLSL(UU1,R)*UU1**QQ
      P2=YLSL(UU2,R)*UU2**QQ
      SUM=SUM+(P1+P2)/B
      IF(IFLAG.EQ.1) GO TO 4
      U1=U2
      GO TO 2
    4 YDRL=YDRL+(Q-1.)*SUM/(Q*Q*X**(1./Q))
      RETURN
      END
```

```
            FUNCTION YLSL(X,R)
      C
      C        EQUIVALENT WIDTH DERIVATIVE FUNCTION FOR A BAND OF LORENTZ
      C        LINES WITH AN EXPONENTIAL-TAILED INVERSE LINE STRENGTH
      C        DISTRIBUTION AND FOR THE LINDQUIST-SIMMONS APPROXIMATION
      C
            XX=SQRT(1.+2.*X)
   10       YLSL=(2.*R*(1.+X)+(1.+R**2)*XX)/(XX*(R+XX)**2)
   22       RETURN
   22       END
```

```
      FUNCTION YCGD(X,R)
C
C        EQUIVALENT WIDTH DERIVATIVE FUNCTION FOR A BAND OF DOPPLER
C        LINES WITH AN EXPONENTIAL-TAILED INVERSE LINE STRENGTH
C        DISTRIBUTION AND FOR THE CURTIS-GODSON APPROXIMATION
C
      YCGD=1.
 5    IF(X.EQ.0.) RETURN
 7    Z=3.1415927*X
10    YCGD=(2.-R)*YLSD(Z,1.)+(R-1.)*G(Z)/Z
26    RETURN
27    END
```

```
                FUNCTION YMLD(X,R,Q)                                         YMLD   2
      C                                                                      YMLD   3
      C             EQUIVALENT WIDTH DERIVATIVE FUNCTION FOR A BAND OF DOPPLER YMLD   4
      C             LINES WITH AN EXPONENTIAL-TAILED INVERSE LINE STRENGTH   YMLD   5
      C             DISTRIBUTION AND FOR THE MEAN-LINE DERIVATIVE APPROXIMATION YMLD   6
      C                                                                      YMLD   7
      C                                                                      YMLD   8
                YMLD=1.                                                      YMLD   9
   6            IF(Q.EQ.0.) RETURN                                           YMLD  10
  10            IF(X.EQ.0.) RETURN                                           YMLD  11
  13            Z=3.1415927*X/Q                                              YMLD  12
  15            YMLD=YLSD(Z,R)                                               YMLD  13
  20            RETURN                                                       YMLD  14
  20            END
```

```
      FUNCTION YLSD(X,R)
C
C        EQUIVALENT WIDTH DERIVATIVE FUNCTION FOR A BAND OF DOPPLER
C        LINES WITH AN EXPONENTIAL-TAILED INVERSE LINE STRENGTH
C        DISTRIBUTION AND FOR THE LINDQUIST-SIMMONS APPROXIMATION
C
C
C TABULAR INTERPOLATION DATA
      DIMENSION XX(22),WW(8),YY(22,8),S(3)
      DATA(XX(I),I=1,22)/ 1.0E-2, 2.0E-2, 5.0E-2, 1.0E-1, 2.0E-1,
     X      5.0E-1, 1.0E-0, 2.0E-0, 5.0E-0, 1.0E+1, 2.0E+1, 5.0E+1,
     X      1.0E+2, 2.0E+2, 5.0E+2, 1.0E+3, 2.0E+3, 5.0E+3, 1.0E+4,
     X      2.0E+4, 5.0E+4, 1.0E+5/
      DATA(WW(J),J=1,3)  / 0.3333333333, 0.5000000000, 0.5555555556 /
      DATA(WW(J),J=4,6)  / 0.6000000000, 0.6666666667, 0.7500000000 /
      DATA(WW(J),J=7,8)  / 0.8333333333, 1.0000000000               /
      DATA(YY(K),K=  1, 22)/ .99114E+0, .98243E+0, .95723E+0, .91503E+0,
     X .84868E+0, .69248E+0, .53069E+0, .36239E+0, .18622E+0, .10301E+0,
     X .54426E-1, .22344E-1, .11408E-1, .57394E-2, .23038E-2, .11533E-2,
     X .57700E-3, .23088E-3, .11546E-3, .57731E-4, .23093E-4, .11547E-4/
      DATA(YY(K),K= 23, 44)/ .99299E+0, .98608E+0, .96603E+0, .93460E+0,
     X .87828E+0, .74750E+0, .60490E+0, .44564E+0, .25945E+0, .15883E+0,
     X .92598E-1, .43173E-1, .23642E-1, .12759E-1, .55565E-2, .29368E-2,
     X .15432E-2, .65458E-3, .34067E-3, .17676E-3, .73960E-4, .39163E-4/
      DATA(YY(K),K= 45, 66)/ .99380E+0, .98770E+0, .96935E+0, .94207E+0,
     X .89190E+0, .77433E+0, .64392E+0, .49455E+0, .31182E+0, .20643E+0,
     X .13195E+0, .70728E-1, .43542E-1, .26649E-1, .13871E-1, .84594E-2,
     X .51628E-2, .26937E-2, .16503E-2, .10132E-2, .53344E-3, .32916E-3/
      DATA(YY(K),K= 67, 88)/ .99450E+0, .98907E+0, .97329E+0, .94846E+0,
     X .90367E+0, .79739E+0, .67937E+0, .54100E+0, .36533E+0, .25986E+0,
     X .18653E+0, .10935E+0, .75384E-1, .51787E-1, .31709E-1, .21932E-1,
     X .15322E-1, .95640E-2, .67263E-2, .47468E-2, .30083E-2, .21370E-2/
      DATA(YY(K),K= 89,110)/ .99556E+0, .99119E+0, .97844E+0, .95836E+0,
     X .92200E+0, .83553E+0, .73706E+0, .61957E+0, .46432E+0, .35450E+0,
     X .28411E+0, .20490E+0, .16102E+0, .12735E+0, .94277E-1, .75569E-1,
     X .60853E-1, .45971E-1, .37322E-1, .30380E-1, .23224E-1, .18996E-1/
      DATA(YY(K),K=111,132)/ .99686E+0, .99377E+0, .98474E+0, .97050E+0,
     X .94464E+0, .88273E+0, .81132E+0, .72444E+0, .60548E+0, .52441E+0,
     X .45506E+0, .38046E+0, .33469E+0, .29611E+0, .25358E+0, .22568E+0,
     X .20319E+0, .17650E+0, .15906E+0, .14358E+0, .12570E+0, .11393E+0/
      DATA(YY(K),K=133,154)/ .99805E+0, .99613E+0, .99053E+0, .98158E+0,
     X .96560E+0, .92592E+0, .88198E+0, .82669E+0, .74932E+0, .69430E+0,
     X .64664E+0, .59211E+0, .55672E+0, .52535E+0, .48873E+0, .45396E+0,
     X .44126E+0, .41390E+0, .39491E+0, .37718E+0, .35546E+0, .34018E+0/
      DATA(YY(K),K=155,176)/ .10000E+1, .10000E+1, .10000E+1, .10000E+1,
     X .10000E+1, .10000E+1, .10000E+1, .10000E+1, .10000E+1, .10000E+1,
     X .10000E+1, .10000E+1, .10000E+1, .10000E+1, .10000E+1, .10000E+1,
     X .10000E+1, .10000E+1, .10000E+1, .10000E+1, .10000E+1, .10000E+1/
C
C TABULAR INTERPOLATION FUNCTIONS
      AA(Y1,Y2,Y3,X1,X2,X3)=(ALOG(Y3/Y2)/ALOG(X3/X2)-ALOG(Y2/Y1)/ALOG(X2
     X/X1))/ALOG(X3/X1)
      BB(Y2,Y3,X2,X3,A)=ALOG(Y3/Y2)/ALOG(X3/X2)-A*ALOG(X3/X2)
C
C
      Z=X
C SMALL X APPROXIMATION
```

```
 72         IF(Z.GT.0.01) GO TO 1                                              YLSD
 76         YLSD=1.-Z/SQRT(1.+R**2)+Z**2/SQRT(1.+2.*R**2)                      YLSD
117         RETURN                                                             YLSD
      C LARGE X APPROXIMATION                                                  YLSD
117       1 IF(Z.LE.10000.) GO TO 2                                            YLSD
122         YLSD=0.                                                            YLSD
123         RETURN                                                             YLSD
      C SMALL R APPROXIMATION                                                  YLSD
123       2 IF(R.GE.0.5) GO TO 3                                               YLSD
126         YLSD=1./SQRT((1.+Z)*(1.-7*(R**2-1.)))                              YLSD
137         RETURN                                                             YLSD
      C LARGE R APPROXIMATION                                                  YLSD
140       3 IF(R.LE.10000.) GO TO 4                                            YLSD
143         YLSD=1.                                                            YLSD
144         RETURN                                                             YLSD
145       4 CONTINUE                                                           YLSD
      C                                                                        YLSD
      C TABULAR INTERPOLATION FOR INTERMEDIATE X AND R                         YLSD
145         DO 5 I=1,27                                                        YLSD
153         IF(Z.LE.XX(I)) GO TO 6                                             YLSD
155       5 CONTINUE                                                           YLSD
157       6 N=I-1                                                              YLSD
161         IF(N.LE.1) N=2                                                     YLSD
164         W=R/(1.+R)                                                         YLSD
167         DO 7 J=1,8                                                         YLSD
174         IF(W.LE.WW(J)) GO TO 8                                             YLSD
176       7 CONTINUE                                                           YLSD
200       8 M=J-1                                                              YLSD
202         IF(M.LE.1) M=2                                                     YLSD
205         DO 9 K=1,3                                                         YLSD
207         L=N-2+K                                                            YLSD
211         A=AA(YY(L,M-1),YY(L,M),YY(L,M+1),WW(M-1),WW(M),WW(M+1))            YLSD
226         B=BB(YY(L,M),YY(L,M+1),WW(M),WW(M+1),A)                            YLSD
242         C=ALOG(YY(L,M))                                                    YLSD
251       9 S(K)=EXP(A*ALOG(W/WW(M))**2+B*ALOG(W/WW(M))+C)                     YLSD
270         A=AA(S(1),S(2),S(3),XX(N-1),XX(N),XX(N+1))                         YLSD
302         B=BB(S(2),S(3),XX(N),XX(N+1),A)                                    YLSD
313         C=ALOG(S(2))                                                       YLSD
316         YLSD=EXP(A*ALOG(Z/XX(N))**2+B*ALOG(Z/XX(N))+C)                     YLSD
332         RETURN                                                             YLSD
332         END                                                                YLSD
```

```
                FUNCTION YMIX(WD,WL,WW,WV,YD,YL)
          C
          C         COMPUTE DERIVATIVE FUNCTION Y FOR A VOIGT LINE BY A
          C         COMBINATION OF DERIVATIVE FUNCTIONS AND EQUIVALENT
          C         WIDTHS FOR PURE LORENTZ AND DOPPLER LINE SHAPES
          C         ACCORDING TO THE NASA HANDBOOK APPROXIMATION.
          C
                YMIX=1.
     11         IF(WV.EQ.0.) RETURN
     15         RL=(WL/WW)**2
     16         RD=(WD/WW)**2
     17         RV=(WV/WW)**2
     21         Y=1./(1.-RL)**2+1./(1.-RD)**2-1.
     31         DL=(SQRT(Y)*(1.-RL))**3
     35         DD=(SQRT(Y)*(1.-RD))**3
     50         A=(WL/WV)/DL
     52         B=(WD/WV)/DD
     54         C=(WW/WV)*(RV-(RL/DL+RD/DD))
     61         YMIX=A*YL+B*YD+C
     65         RETURN
     65         END
```

```
      FUNCTION F(X)
C
C         CURVE OF GROWTH FUNCTION FOR A BAND OF LORENTZ LINES
C         WITH AN EXPONENTIAL-TAILED INVERSE LINE STRENGTH
C         DISTRIBUTION.
C
      F=0.3183099*(SQRT(1.+6.283185*X)-1.)
      RETURN
      END
```

```
      FUNCTION G(X)
C
C          CURVE OF GROWTH FUNCTION FOR A BAND OF DOPPLER LINES
C          WITH AN EXPONENTIAL-TAILED INVERSE LINE STRENGTH
C          DISTRIBUTION
C
C TABULAR INTERPOLATION DATA
      DIMENSION XX(21),GG(21)
      DATA(XX(I),I=1,21) / 1.0E-1, 2.0E-1, 4.0E-1, 6.0E-1, 8.0E-1,
     X     1.0E-0, 2.0E-0, 4.0E-0, 6.0E-0, 8.0E-0, 1.0E+1, 2.0E+1,
     X     4.0E+1, 6.0E+1, 8.0E+1, 1.0E+2, 2.0E+2, 4.0E+2, 6.0E+2,
     X     8.0E+2, 1.0E+3/
      DATA(GG(I),I=1,21) /   .9664 5E-1, .18722E-0, .35325E-0, .51289E-0,
     X .63940E-0, .76515E-0, .12814E+1, .20057E+1, .25279E+1, .29414E+1,
     X .32857E+1, .44796E+1, .58466E+1, .67192E+1, .73687E+1, .78891E+1,
     X .95938E+1, .11423E+2, .12548E+2, .13369E+2, .14019E+2/
C
C TABULAR INTERPOLATION FUNCTIONS
      AA(Y1,Y2,Y3,X1,X2,X3)=(ALOG(Y3/Y2)/ALOG(X3/X2)-ALOG(Y2/Y1)/ALOG(X2
     X/X1))/ALOG(X3/X1)
      BB(Y2,Y3,X2,X3,A)=ALOG(Y3/Y2)/ALOG(X3/X2)-A*ALOG(X3/X2)
C
C SERIES SOLUTION FOR SMALL X
      Z=3.1415927*X
67    IF(Z.GT.0.1) GO TO 1
73    G1=1.000000+0.192450*Z**2+0.089443*Z**4
77    G2=0.353553*Z+0.125000*Z**3+0.06801*Z**5
106   G=Z*(G1-G2)/3.1415927
112   RETURN
C
C ASYMPTOTIC EXPANSION SOLUTION FOR LARGE X
112 1 IF(Z.LT.1000.) GO TO 2
115   G=0.23945*ALOG(Z)**1.5*(1.+1.2337/ALOG(Z)**2+1.0654/ALOG(Z)**4)
131   RETURN
C
C TABULAR INTERPOLATION FOR INTERMEDIATE X
131 2 DO 3 I=1,21
137   IF(Z.LE.XX(I)) GO TO 4
141 3 CONTINUE
143 4 N=I-1
145   IF(N.LE.1) N=2
150   A=AA(GG(N-1),GG(N),GG(N+1),XX(N-1),XX(N),XX(N+1))
162   B=BB(GG(N),GG(N+1),XX(N),XX(N+1),A)
173   C=ALOG(GG(N))
176   G=0.318310*EXP(A*ALOG(Z/XX(N))**2+B*ALOG(Z/XX(N))+C)
213   RETURN
213   END
```

```
      FUNCTION WMIX(WD,WL,WW)
C
C         COMPUTE EQUIVALENT WIDTH W FOR A VOIGT LINE BY A
C         COMBINATION OF EQUIVALENT WIDTHS FOR PURE LORENTZ
C         AND DOPPLER LINES ACCORDING TO THE NASA HANDBOOK
C         APPROXIMATION.
C
      WMIX=0.
5     IF(WW.EQ.0.) RETURN
10    Y=1./(1.-(WL/WW)**2)**2+1./(1.-(WD/WW)**2)**2-1.
15    WMIX=WW*SQRT(1.-1./SQRT(Y))
31    RETURN
32    END
```

END

DATE
FILMED

5 81

DTIC